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AMOS PHASE IV ANNUAL REPORT

AVCO Everett Research Laboratory, Inc.

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APPROVED: *James W Cusack*

JAMES W. CUSACK
Project Engineer

AMOS PHASE IV ANNUAL REPORT

Dr. J. Chapman
Dr. P. McCormick
AMOS Staff

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RADC Project Engineer:
    James W. Cusack/RADC/OCSE - (315)330-3145
    Capt Gary Dahlen/RADC/OL.-AB - (808)877-6594

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This technical report summarizes the activities which have occurred at the ARPA Maui Optical Site (AMOS) during the period 1 Jan 79 through 31 Dec 79. These activities have taken advantage of the AMOS facility which was developed by ARPA and now serves as a multi-purpose advanced optical testbed. This report contains a complete summary of the development of AMOS, a description of the assets available and summarizes the major accomplishments.

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1.0 INTRODUCTION

This report describes progress, status and important accomplishments and findings pertaining to the specific tasks that together comprise the AMOS (ARPA Maui Optical Station) Phase IV Program. The period covered is 1 January through 31 December 1979.

The document is divided into four sections. Section 1 is an introduction. Section 2 gives a brief background of the AMOS facility and summarizes the major accomplishments of previous phases. Section 3 addresses the Phase IV program by first describing the assets available (i.e. the hardware and software systems and capabilities) and then discussing the basic program objectives. Section 4 is a summary of significant results and accomplishments achieved during the first two years of the Phase IV program and a statement of the important conclusions that can be drawn from these results.

The intent is that Sections 2 and 3 will allow the reader to obtain a basic knowledge of AMOS capabilities and, in particular, a clear understanding of the overall goals and major accomplishments of the Phase IV Program to date.

Section 4 discusses, in detail, progress on specific Phase IV tasks during 1979 and is keyed to the Statement of Work.

2.0 BACKGROUND

The DARPA-sponsored AMOS program has included four phases. Highlights of the first three are given in this section. The fourth is the subject of the remainder of the report.

Phase I spanned the period 1963-1969 and included conception, design, and construction of the basic facility. The University of Michigan was the Phase I contractor. The 1.6 m and twin 1.2 m Telescopes were specified, fabricated, installed and tested. A Control Data Corporation (CDC) 3200 computer, along with first generation pointing and tracking software, was integrated into the facility. Sensors included an IR array for tracking, IR sensor for signature measurements, a low radiance pulsed ruby laser and various imaging devices (e.g. image orthicons and film cameras). The first link to an off-island radar was implemented during this period (Kokee Park on Kauai). Although a significant amount of data was obtained on satellites and missiles, Phase I is best described as a period of hardware installation and debugging and development of basic techniques. Phase I, however, clearly demonstrated the potential importance of AMOS and defined directions for the future.

The second phase was from mid-1969 to the end of 1974. Funding came from DARPA via SAMSO. Two contractors were responsible for the program; AVCO Everett Research Laboratory

for technical direction and Lockheed Missiles & Space Company
for operations, maintenance and development. During Phase II,
major improvements were made to test bed and sensor systems.
A new computer system, based upon a CDC 3500/SC-17, was installed
which greatly increased AMOS capability and versatility. To
augment this hardware, AMOS staff members produced sophisticated
new software which allowed simultaneous dual-mount operation
along with Kalman Filter-smoothed tracking. Absolute pointing
was greatly improved by the development and refinement of mount
models. A second radar (Kaena Point on Oahu) was interfaced to
AMOS which allowed skin as well as beacon tracking. The
original IR tracker was replaced with the state-of-the-art AMTA
(Advanced Multi-Color Tracker for AMOS) system which immediately
began to provide important signature data. Implementation of
AMTA required conversion of the original 1.2 m, B0 Telescope to
a B29 configuration (f/20). A high radiance ruby laser was
specified, fabricated and installed on what was then the 1.2 m,
B30 Telescope. This system was used to obtain ranging data on
retro-reflector equipped satellites and to develop techniques
and define improvements necessary to fully exploit laser
ranging at AMOS. An outgrowth of this effort was the specifi-
cation and design of a Laser Beam Director (LBD) facility which
was then implemented during Phase III. Improvements in AMOS
imaging systems kept pace with the state-of-the-art.

It was during Phase II that AMOS began to routinely provide high-quality data of importance to DoD. Metrics and IR measurements were conducted in support of the MMII, MMIII, HAVE LENT and REVTO programs. IR and visible signatures were obtained on various classes of satellites. Thermal balance techniques were applied with great success to RORSAT objects. In short, by the end of Phase II, AMOS had successfully made the transition from a university research laboratory to an efficient state-of-the-art DoD measurement facility.

Phase III began in January of 1975 and continued to the end of 1977. AVCO Everett Research Laboratory, Inc. was the sole Phase III contractor. Funding again came from DARPA but RADC replaced SAMSO as fiscal agent. Phase III consisted of operations and measurements programs with an overlay of research and development activity.

Measurements continued on MMII and MMIII systems (metrics), HAVE LENT objects (IR masking), and satellites (metrics, signatures). The laser was used for ranging on geodetic satellites and illumination of special targets. Atmospheric characterization hardware was installed and accumulation of a data base was initiated in support of the DARPA Compensated Imaging program. Many special measurement activities occurred during Phase III in areas such as IR and visible radiometry, atmospherics and target signature analysis.

Basic AMOS capabilities were greatly improved during Phase III, as hardware and software modifications continued to be implemented. These improvements were outgrowths of AMOS experience during the first two phases and concentrated heavily on refinement and optimization of existing systems in addition to installation of new and/or modified hardware and software. Phase III improvements included the following:

1) installation of diffraction-limited optics in the 1.6 m Telescope;

2) installation/evaluation of the Laser Beam Director (LBD) facility;

3) incorporation of the ruby laser into the beam director;

4) new primary mirror support systems for the large optics;

5) implementation of beamsteering on the 1.2 m Telescopes;

6) provision of additional instrument mounting surfaces;

7) design and implementation of a contrast mode photometer;

8) upgrading of all video imaging systems;

9) specification of new acquisition telescopes; and

10) development of long term integration and background characterization hardware for AMTA.

It was also during Phase III that DARPA initiated the transition of a portion of the AMOS facility to Aerospace Defense Command (ADCOM). Hardware systems involved included the 1.2 m Telescopes along with their sensors and support equipment. The CDC 3500 was considered as shared equipment, and new hardware and software systems were developed to allow timely reduction and transmittal of large amounts of data. The ADCOM portion of the complex is known as the MOTIF (Maui Optical Tracking and Identification Facility) and became a part of the SPACETRACK network in August of 1979.

By the end of 1977, AMOS had existed for over a decade and had gone through three distinct phases of development. The result was a national asset that can be briefly described as "an advanced electro-optical facility to support critical DoD measurement and development programs operating in a unique environment."

The facility is equipped with state-of-the-art sensors and a sophisticated and versatile computer complex which allows high precision pointing and tracking with the AMOS large aperture optical systems.

3.0   SUMMARY

The AMOS Phase IV program began on 1 January 1978 and
ends on 30 September 1980   The objectives of the program
have certain important differences from those of the prior
three phases.   In this section we first describe the systems
and capabilities available to accomplish the Phase IV objec-
tives.   This is followed by a summary of the objectives them-
selves.   The section concludes with a discussion of important
results and accomplishments that have been realized during
the first two years of the Phase IV program.

3.1   Phase IV Systems

To properly understand the goals and accomplishments of
the Phase IV program to date, it is important to have a general
knowledge of the hardware and software systems either dedicated
or available.   These systems are briefly described below:

1)   Facility

AMOS is located on the island of Maui, Hawaii.
The observatory facility is situated at an altitude
of 3,049 meters (10,000 feet) on the crest of Mount
Haleakala.   This high altitude location, in a rela-
tively stable climate of dry air with low levels of
particulate matter and scattered light from surface
sources, provides excellent conditions for the
acquisition and viewing of space objects.

Figure 3-1 shows an exterior view of the
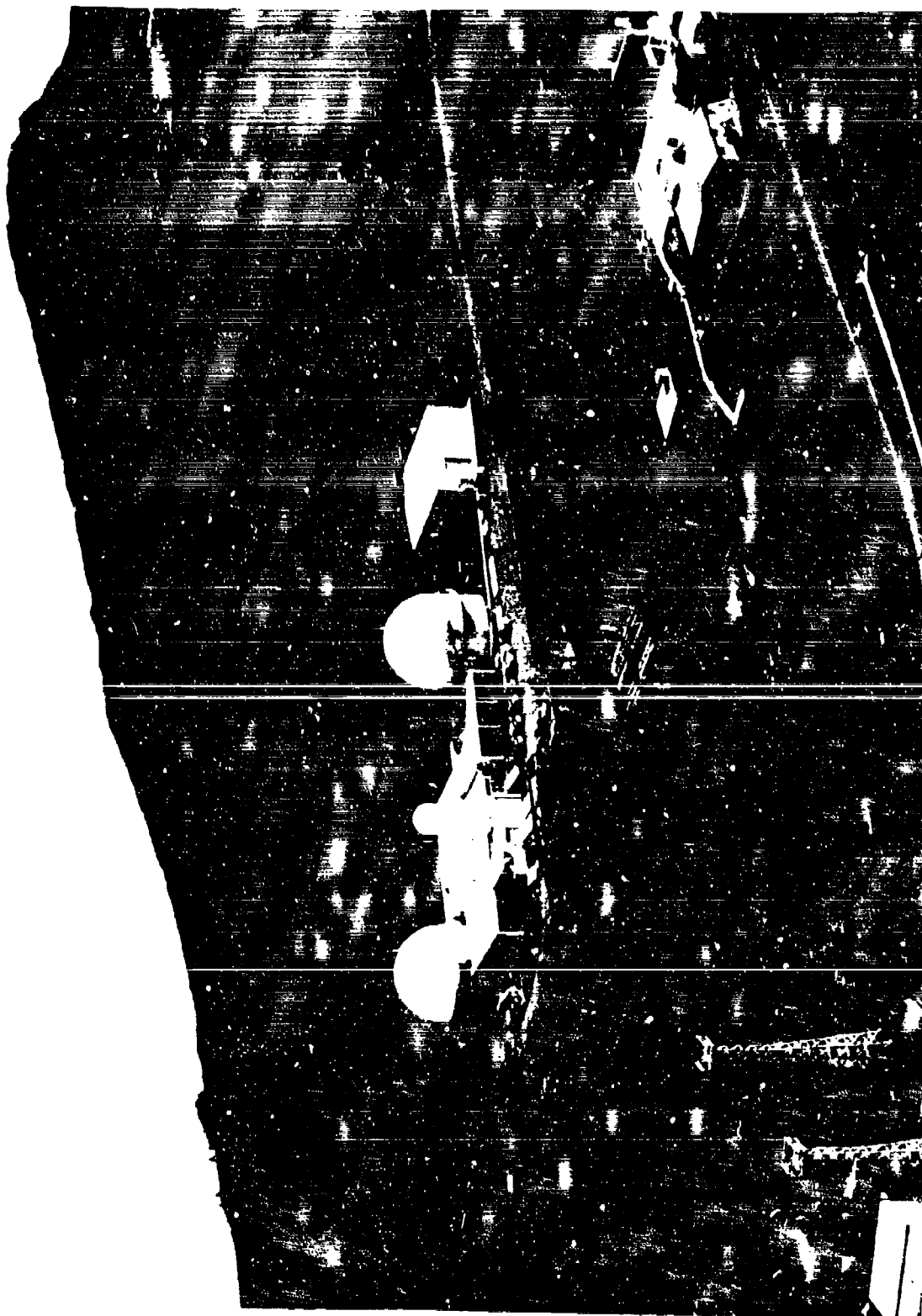
Figure 3-1. Aerial view of AMOS facility.

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facility. From the left of the figure, the domes are for the 1.2 m Telescopes, the Laser Beam Director, atmospheric instrumentation and the 1.6 m Telescope, respectively.

2) 1.6 Meter Telescope

The AMOS 1.6 m Telescope allows diffraction-limited performance (approximately 0.1 arcsecond resolution) at all mount attitudes above the horizon. The clear aperture is 1.57 m and the effective focal length is 25 m. Two instrument mounting surfaces are available for sensor packages. The rear Blanchard surface will be dedicated to the DARPA Compensated Imaging System (CIS) in 1980. Once this system is installed and operational, system performance should approach the resolution stated above instead of the current 0.5 to 1 arcsecond limit set by typical AMOS "seeing" conditions. The side Blanchard surface supports a classical sensor package which currently includes the laser receiver, a 16 mm film camera, an Intensified Silicon Intensifier Target (ISIT) camera and a visible radiometer. Broadband mirror coatings (Al plus an SiO overcoat) allow spectral coverage from the visible through the LWIR. INVAR metering rods maintain basic intermirror spacing and a computer

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controlled autorange system is included. The primary mirror is supported axially with a three-segment airbag and radially with a mercury-filled belt to minimize aberrations and maintain optical alignment.

The mount has fully hydrostatic bearings, a 23-bit shaft shaft angle encoder and is servo-driven by direct current torque motors under computer control. This system allows absolute pointing to about 3 arcseconds rms and tracking to approximately 1 arc-second rms at slewing velocities up to several degrees per second and accelerations to 2 degrees per second^2.

The AMOS 1.6 m mount, shown in Figure 3-2, provides a unique and valuable capability for electro-optical research and development programs.

3) Laser Beam Director

The Laser Beam Director (LBD) was installed during Phase III and provides a versatile pointing and tracking system for use with lasers. The system consists of a 24-inch diameter beam expander (designed for an input beam of 4-inch diameter) mounted on an azimuth turntable and coupled to a 36-inch diameter Beryllium tracking flat. The tracking flat is mounted on an azimuth/elevation gimbal which receives data

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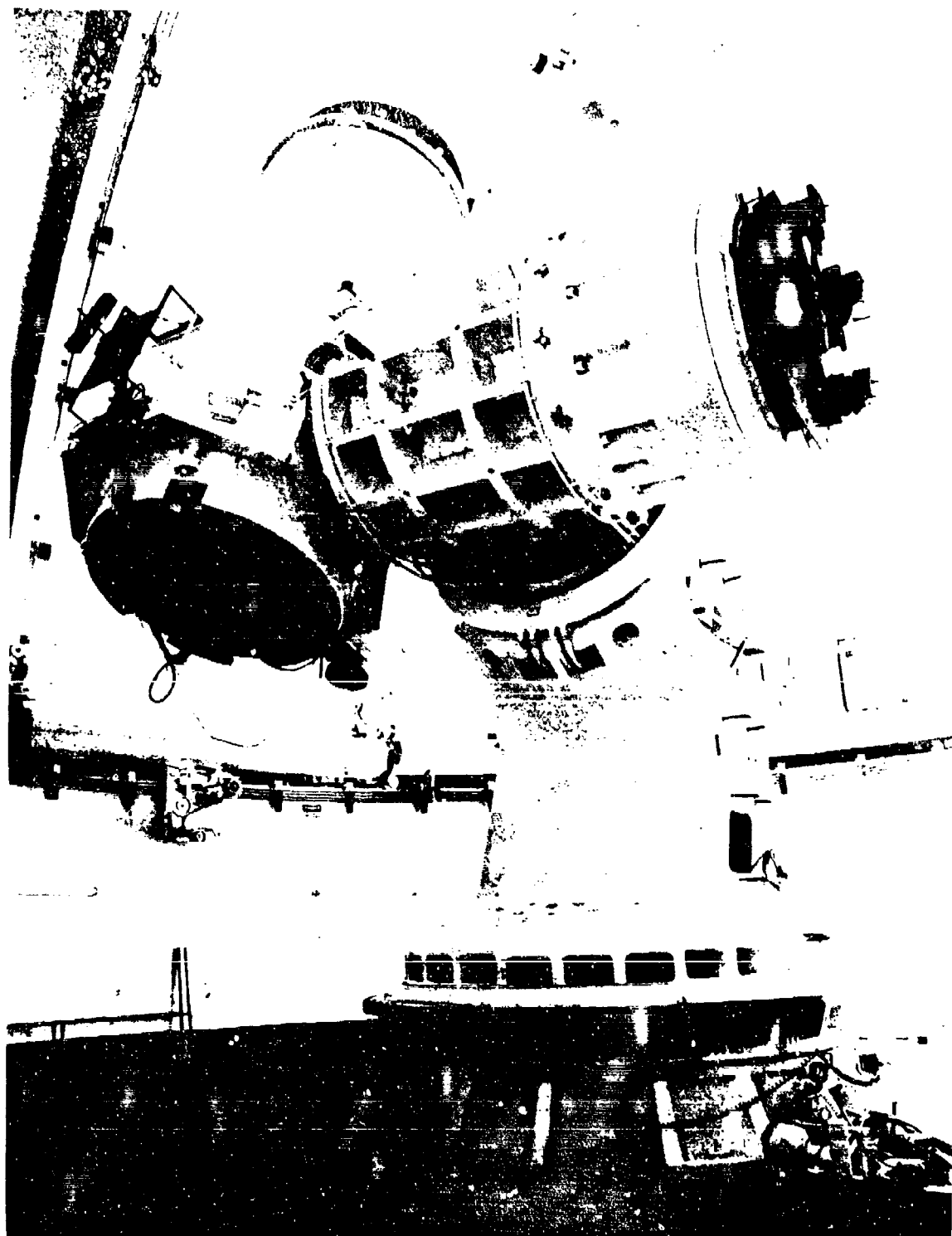
Figure 3-2.   1.6 meter mount.

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from the CDC 3500 computer. The pointing and tracking performance of this system is essentially the same as that of the 1.6 m Telescope. The optics are currently optimized for the ruby laser but can be easily modified for other wavelengths.

Versatility was designed into the LBD. During the first year of Phase IV, for example, a special pulsed ruby laser supplied by a user organization was coupled into the system and made available for operations within two days.

A photograph of the LBD is shown in Figure 3-3.

4) Pulsed Ruby Laser

The AMOS pulsed ruby laser ($\lambda = 0.694$ microns) occupies one channel of the LBD. When operated at 20 pulses per minute, the output beam divergence from the 24-inch beam expander can be adjusted to about 2 arcseconds. Q-switched outputs of 10 Joules per 25 nanosecond pulse are used for ranging with precisions of about ± 2 m on cooperative targets. Conventional mode operation at the 80 Joule level per 1 millisecond pulse provides an illumination capability. This system has been modified for the LBD Phase II Program as discussed in Section 4.9.

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GIMBALED
TRACKING
MIRROR

BEAM EXPANDER
SECONDARY MIRROR
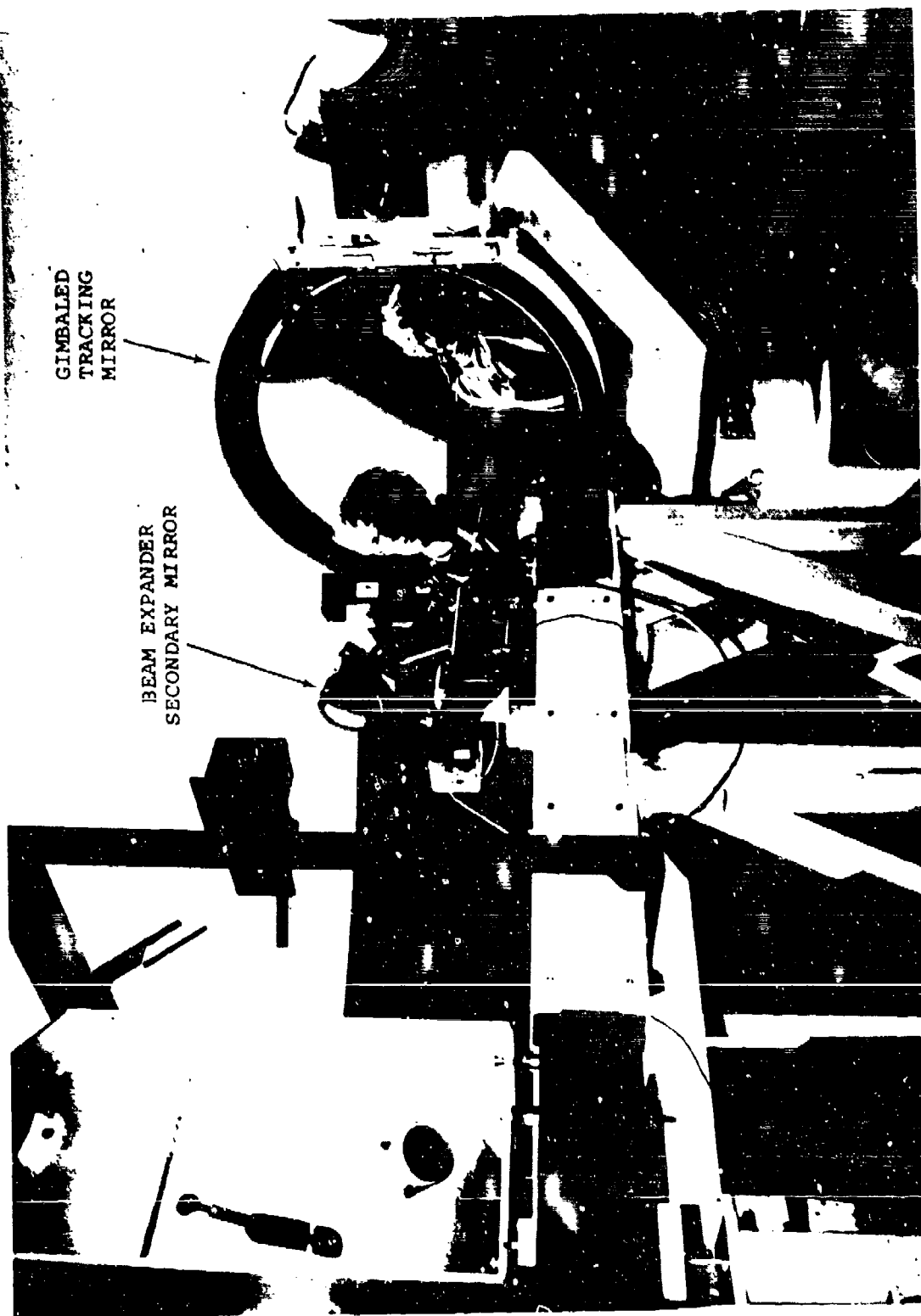
Figure 3-3. Laser beam director.

5) Visible Radiometry

A visible-light radiometer is installed on the 1.6 m Telescope and is equipped with various spectral and neutral density filters and adjustable fields-of-view. This system, when operated against a dark night sky, can observe point sources as faint as +18 m_v with a reasonable signal-to-noise ratio. The system is used to measure target radiance and dynamics.

6) Video Systems

All of the large optical systems are equipped with ISIT cameras (looking through the prime optics) which can be coupled to digital integration and averaging devices. The system installed on the 1.6 m Telescope has been used to photograph a star of apparent visual magnitude (m_v) +19.5 against a dark night sky. Although these cameras are used primarily to obtain metric data, they can, for example, be used for measurements such as laser illumination.

7) Acquisition Telescopes

A significant capabilities enhancement became operational on both the 1.2 m and 1.6 m mounts during 1979 in the form of improved telescope systems for target acquisition. These new systems replaced the existing 18.6-inch system on the 1.2 m Telescope (which provided 3° and 23' fields-of-view) and the single 1°

field-of-view, 10-inch telescope used on the 1.6 m
mount.

With the new AMOS Acquisition Telescope System
(AATS), the 1.6 m mount now has three selectable fields,
3°, 0.5° and 0.1°. The 3° field is an f/6 system with
an eight inch aperture while the smaller two fields
have a 22 inch diameter collecting aperture.

Both new AATS are fitted with large format ISIT
TV sensors which provide state of the art sensitivity
consistant with the respective photon collecting areas.
The wide field system can detect +11 m_v stars while
the two narrower field systems are capable of seeing
objects as faint as +16 m_v. The AATS mounted on
the side of the 1.6 m Telescope can be seen in
Figure 3-4.

8) High Resolution Imaging

The prime sensor for high resolution imaging is a
16 mm film camera located on the side Blanchard surface
of the 1.6 m Telescope. This system is currently
involved in obtaining a classical imaging data base as
a part of the CIS program. Photographs obtained with
this hardware are included in Section 4.3.3.2.

9) LWIR Radiometry

Although the AMTA system is now a part of the
MOTIF, it is also available to support Phase IV

AATS   1.6m TELESCOPE

Figure 3-4. AATS on 1.6m telescope.

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programs under special tasking.

AMTA consists of a 25-element infrared sensor array mounted directly on the rear Blanchard surface of the 1.2 m B29 Telescope in the west dome. The sensor consists of reimaging optics, servo-driven scan mirror, filter wheel assembly, 25-element Ge:Cd detector array, detector preamplifiers, cryogenic refrigerator dewar, and associated electronics. A beamsplitter separates the visible and infrared energy. The visible energy is imaged into a TV camera which serves as an acquisition and pointing aid for the system.

The data is recorded on analog and digital magnetic tape. Recorded are all 25 detectors, a reference calibration, filter position, photometer signal, IRIG B timing and a voice track.

The AMTA sensor permits AMOS to obtain low dispersion spectral data on targets of interest in atmospheric windows between 2 and 21 microns and to perform manual or closed-loop tracking of targets utilizing real-time position information. The infrared spectral coverage includes 7 bands in the 2 to 21 micron range. The ratio of the signals recorded can be correlated with the temperature of objects of

interest. Thermal changes can be determined as the observed body is presented in varying lighting conditions.

10) Atmospheric Instrumentation

The data output from several atmospheric characterization instruments can be provided to support other data measurements at AMOS. The site supports a continuing Atmospheric Characterization Program (ACP) whose data can provide information on imaging with a large aperture system in the presence of atmospheric turbulence and allow evaluation of turbulence effects on other types of instrumentation operated at AMOS.

The instrumentation installed at the site includes:

    1) Microthermal Probe System;

    2) Acoustic Sounder;

    3) Star Sensor; and

    4) Seeing Monitor.

The instrumentation, much of it one-of-a-kind prototype, has resulted from previous studies funded by DARPA/RADC. The sensors were designed to provide information on turbulence at low levels (20 m above AMOS the site), intermediate levels (30 to 300 m), higher levels ranging to the tropopause and finally

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through the whole atmosphere.

Routine meteorological instrumentation mounted
on towers, removed from the basic building structure,
record wind speed and direction, ambient temperature
and dew point temperature. Atmospheric pressure is ---
obtained from a mercury barometer.

An All-Sky Camera (ASC) automatically records sky
conditions 24 hours per day.

11) Computer System

The primary function of the AMOS computer system
is to provide real-time control of the telescope
mounts and Laser Beam Director. The system must
calculate, in real-time, target position as a function
of nominal ballistic data. It must, in real-time,
assimilate radar tracking data and data from a variety
of other sensors; compute mount model corrections due
to mount anomalies; determine mount position and
generate output error signals to the servo systems;
respond to real-time perturbations that may be imposed
by the test director; and collect and record data for
nonreal-time reduction.

The AMOS computer system consists of a medium
size general purpose CDC 3500 computer, an SC-17
sequence controller, a buffer transfer unit (BTU),
and 1500 series peripheral equipment.

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A 65K-word memory, of 24 bits per word, is
utilized with the CDC 3500. The primary task of this
computer is to perform real-time trajectory calculations
and optimize trajectory determination by application of
the Kalman Filter to estimated state vectors updated
by observed inputs. Capabilities for processing of
multiple state vectors (targets), multiple radars
(tracking), AMOS sensor inputs and external interrupts
from the test conductor are also available in this
computer. Other functions of the CDC 3500 computer
include coordinate transformations, numerical
integration, mount model, and other extensive calcu-
lations which involve floating point or transcendental
functions.

The SC-17 sequence controller is particularly
adapted to real-time data acquisition and A/D systems
applications. Thus, this unit is the controller of
real-time events and processor of operator commands
and SC-17 peripheral data which do not require processing
by the CDC 3500 computer.

The above paragraphs describe the basic hardware
and software systems that are being used to accomplish
the AMOS Phase IV Program goals - to which we now turn
out attention.

3.2　Phase IV Objectives

The AMOS Phase IV Program consists, in a contractual sense, of various tasks to be accomplished by AERL. Figure 3-5, for example, shows these tasks in the form of a Work Breakdown Structure (WBS) which is useful for program management and control prurposes.

Certain tasks (e.g., system testing, maintenance, calibration and data reduction) represent well defined arcas of activity designed to maintain the AMOS resource at its current level of performance. All of these activites are essential if the major hardware/software systems are to be operated effectively.

Other tasks represent the real return for DARPA's investment in AMOS. The Measurement Program includes those activities which, using existing or slightly modified AMOS capabilities, provide state-of-the-art support to Government user agencies. The area of Visiting Experiments encompasses activities that involve an individual or group wishing to use AMOS systems and capabilities to augment their programs. Large System Test Support represents implementation and exploitation of major DARPA programs initiated during Phase III.

A statement of the Phase IV objectives could, therefore, be made by including a description of the requirements for each of the individual tasks. This approach, however, would not
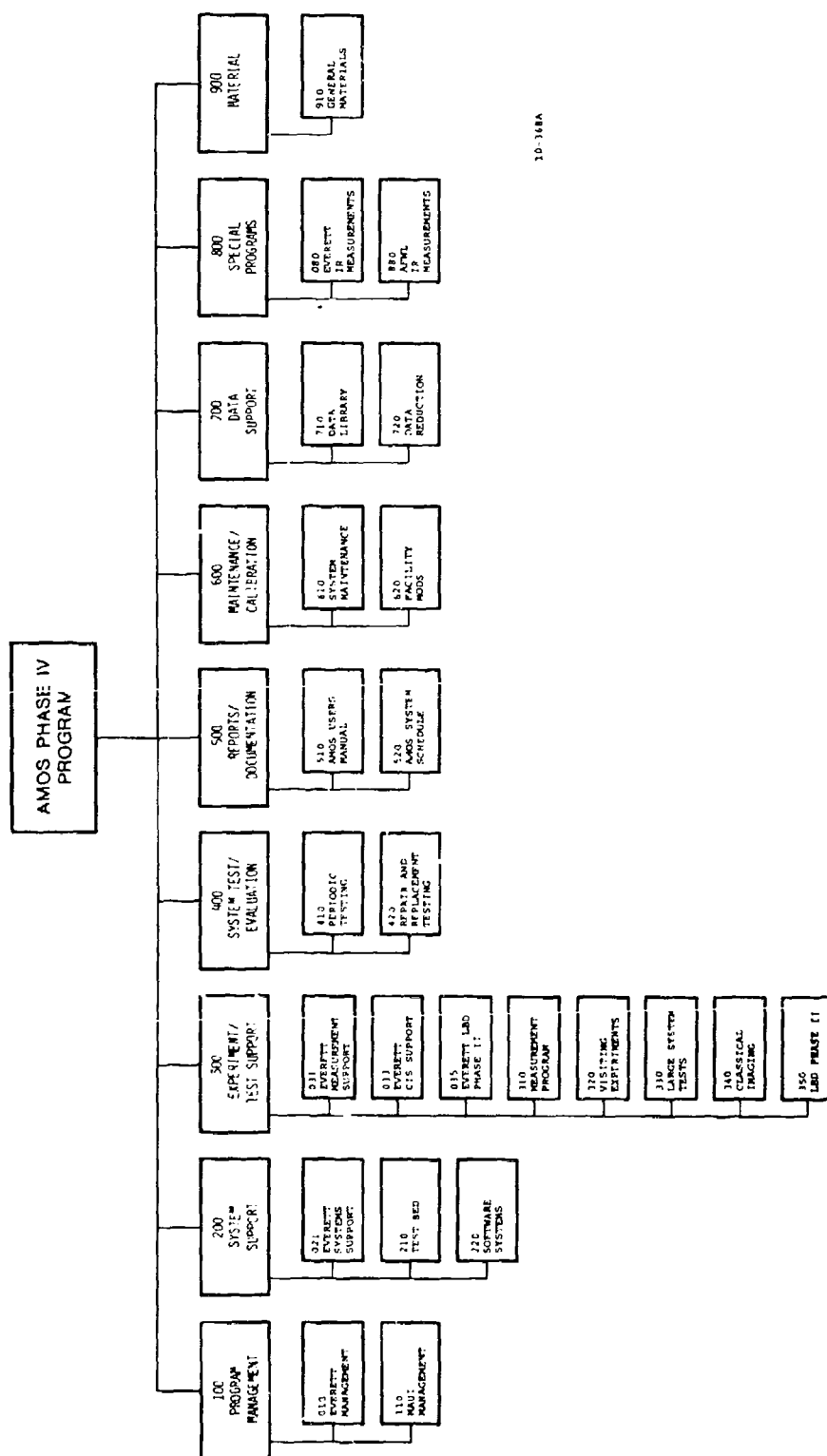
Figure 3-5. AMOS Phase IV work breakdown structure (WBS).

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clearly reveal the fundamental goals of the Phase IV Program which are far more simply and better stated as follows:

1) **EXPLOITATION OF EXISTING CAPABILITIES**

   Use the high-quality systems and techniques developed during previous phases to support DoD measurement objectives (visiting experiments, measurement programs).

2) **EVALUATION OF NEW TECHNOLOGIES**

   Use the inherent AMOS capability and versatility to test, evaluate and bring to operational status various state-of-the-art DoD technologies (DARPA compensated imaging system, advanced electro-optical devices).

3) **IMPROVEMENT OF BASIC CAPABILITIES**

   Continue to improve the performance of test bed and sensor systems and develop new measurement and analysis techniques in order to assure that AMOS keeps pace with the demands of 1 and 2 (improved target state vectors for handoff).

Accomplishment of these three objectives is the real purpose of the AMOS Phase IV Program and any success that is achieved on the individual tasks that comprise the program must be judged accordingly.

3.3 Results, Accomplishments and Conclusions

This section summarizes important results and accomplishments that have been achieved during the first two years of the AMOS Phase IV Program.

In order to emphasize the connection between the work actually being conducted during Phase IV and the general goals discussed in Section 3.2, the approach taken here is to combine the results of individual tasks under a few general headings. Section 4 gives detailed descriptions of the individual tasks keyed to the Statement of Work.

1) Measurement Programs

As emphasized in Section 3.2, one of the basic Phase IV objectives is to fully exploit AMOS capabilities in support of critical DoD measurement programs. This objective was certainly satisfied during the last two years.

Two periods (March and October of 1978) of measurements were conducted in support of the SAMSO Evaluation Program (SEP). Data obtained during March was reduced and published in two classified reports (AERL-78-167 and AERL-78-179). Data obtained in October was degraded by unfavorable weather conditions and was not reduced. To support these measurements, AERL incorporated a major improvement into the AMTA IR measurement system which has resulted in a 30-fold

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reduction in scan noise.

Three Western Test Range (WTR) launches were supported by AMOS to obtain data for the U.S. Army Ballistic Missile Defense (BMD) program. The prime sensor was the AMTA IR measurements system operating in the 8-9 micron and 10-13 micron spectral bands. Primary interests were target signatures and determination of target color temperature. Data and conclusions are contained in a classified report (AERL-78-398).

Several HAVE LENT IV planning meetings were held in 1978 and early 1979. The program consists of two Sergeant-Hydac sounding rocket flights launched from Kauai Test Facility, Barking Sands, Kauai, Hawaii. The two flights scheduled for the morning terminator were to be launched one week apart. AMOS participation in the measurements involved a three mount operation utilizing AMTA, the CMP, the LBD and ruby laser, the 1.6 m CSP photometer and associated TV systems.

The prime objective was to obtain both visible and LWIR signature data and growth rate data on aerosol clouds which would be dispensed from the rockets.

The first launch occurred on the morning of

27 September 1979. The launched vehicle failed to stay within the three sigma bounds of the predicted trajectory. The actual azimuth was reported to be 72 degrees East of the desired trajectory. Both the AN/FPQ-14 and AN/FPS-16 radars lost track and failed to provide AMOS with the necessary pointing data. AMOS did not acquire the vehicle and no measurements of the aerosol clouds were taken. Details of this unsuccessful launch and the subsequent AMOS mount trajectories are presented in Section 4.3.1.1.

The second HAVE LENT IV launch is now scheduled for 15 April 1980 and follows certain corrective action designed to insure a predictable trajectory.

AMOS began a very important new measurement program in the Fall of 1978 to obtain data for the Air Force Weapons Laboratory (AFWL). The overall AFWL goals are:

1) development of an IR adaptive optical system to compensate for atmospheric turbulence;

2) solution of shared aperture problems that arise when using a single system for transmission and reception of radiation; and

3) solving the problem of predicting and correcting for turbulence to be encountered by the transmitted beam.

A major contribution at AMOS to the AFWL program will be to demonstrate the use of an IR detection system to acquire targets without visual or radar assistance. In addition, an IR signature base is being obtained to further define the detection probability for a given search system and scenario.

Measurements began in support of the AFWL program in November 1978. Sky radiance measurements (which can be related to real-time atmospheric transmittance) were completed by the end of the year and a report was prepared. Sky granularity measurements were initiated in December 1978 and completed and documented in 1979. The basic thrust of this work is to investigate the possibility of achieving clutter cancellation in real-time for an appropriate IR sensor.

A third type of measurement activity being conducted by AMOS for the AFWL program involves satellite acquisition statistics and target signatures. Initial measurements provided by this activity produced the beginings of an IR target signature data base for a group of selected targets and in addition, a history of offset tracking information. The offset data was used, in part, to define the field-of-view requirements for an automatic search system. The signature

data will assist in defining the required integration time for the search and provide design information for future, more complex, IR detection systems.

The program also investigates the utilization of AMTA as a target tracker. The B29 scanning secondary mirror was developed to eliminate the cavity noise normally generated by the internal scan mirror system. An automatic search routine will be incorporated into the next phase of measurements. Tracking accuracy will be improved by an order of magnitude by incorporating a modification to the target scan pattern and by the addition of post detection processing. The post-processing will be accomplished by a dedicated Intel 8080 microcomputer. For the brighter satellites, it will be possible to define target position on the array with finer than pixel-limited resolution and provide tracking precision in the realm of 1 to 2 arseconds. Outputs for the twenty-five detectors will be displayed on one of the AMOS TV networks.

In summary, significant measurement support to DoD programs was provided by AMOS during these last two years. Data obtained by the AMOS sensors will be of great value in making long-term decisions regarding

the directions that these and other programs will take
in the future.

2) Visiting Experiments

Another area that received significant attention
and produced important results - during 1978 and
1979 involved support to visiting experiments at
AMOS. Four experiments (Sandia Laser Experiments
I and II, Atmospheric Characterization Program and
the SAMSO HF Laser Experiment) were performed and a
fifth (AFWL IR FLIR Measurements) was initiated.
Also, the possibility of several new experiments was
explored through briefing contacts. These possibi-
lities include a cirrus cloud measurement program,
an electron beam experiment, a metal oxide release
experiment and measurements of an Instrumented Test
Vehicle.

The Sandia Laser Experiments were first initiated
in the Summer of 1975 during which time the capability
to successfully point a ruby laser beam (using the
AMOS Laser Beam Director) at a satellite during the
daytime hours was demonstrated. The objective of the
program was to establish a calibration of the satellite
on-board sensor over the entire diurnal cycle using
laser excitation. Since the satellite could not

be visually acquired during the daytime, pointing was accomplished by means of known orbital elements and an accurate mount model.

The first actual calibration set was accomplished during the period between July 12 and July 22, 1978. Due to the particular pulse waveform requirements imposed by the satellite sensors, a special cooled ruby laser system supplied by Sandia was used in the experiment. Beam forming and pointing was accomplished using the AMOS Laser Beam Director system.

The experiment was successful and was followed in July of 1979 by a second, expanded series which included calibration of two satellites. This second experiment successfully met both the objectives of AMOS and Sandia. All necessary data was collected over a 9-day period. Approximately 600 shots were fired with the Sandia Laser. Half of these resulted in the successful triggering of the Atmospheric Burst Locator (ABL) sensor on the IIA target. The majority of the remaining 300 firings were used during optical alignment of the laser system and to illuminate the IIM target.

In addition to successful accomplishment of the basic experimental goals originally defined for these programs, several valuable results were

obtained that lead to improved AMOS capabilities in
the future.

During the course of the daytime measurements,
it was discovered that the Laser Beam Director was
experiencing severe pointing drifts. It was also
noted, by observation of the return from the retro-
reflectors, that the beam expander system was tending
to defocus in the presence of solar heating. The
pointing drift problems, also a result of solar
heating (particularly on the gimbal system), were
circumvented in real-time by frequent reference to
bright stars which could be observed in the daytime
on Boresight TV. The observed stellar offsets were
then added to the satellite tracking commands.

The ultimate solution to the problem, however,
was to provide protective shielding for both the
20-inch collimator and the gimbals of the 36-inch
tracking flat. Since the collimator is not moved
during satellite tracking, the entire expander system
could be enclosed in a solar reflecting tube which
serves to maintain a uniform temperature throughout
the collimating and beam folding optics. Additionally,
the shaft angle encoders and bearings of the tracking
flat were protected from direct solar illumination
through the use of shields. Further protection was

included by restricting the dome slot width, particularly for the tracking of synchronous satellites.

The program also provided an opportunity to obtain a measure of the far-field intensity pattern of the Laser Beam Director system. With the availability of a feedback link, which provided a direct measure of the relative magnitude of the target irradiance, it was possible to obtain a rough map of the beam pattern. The significant point here is that the satellite sensors provided valuable information on the laser far field intensity profile. This will be extremely useful in predicting the return from noncooperative targets and in tailoring the Laser Beam Director optics to achieve the optimum beam pattern for such targets.

Another rather complex visiting experiment known as the SAMSO HF Laser Experiment and also as the Masking Effects Verification (MEV) program was successfully conducted during August and September of 1979. The experiment involved the use of a hydrogen fluoride laser mounted on the 1.6 m Telescope and some 80,000 pounds of support equipment.

The primary objective of the program was to illuminate certain domestic satellites with a narrow beam of infrared radiation both modulated

and CW. A team of scientists and engineers from both
Aerojet Electro Systems and the Aer space Corporation
were on site during the measurement period. Further
details of the experiment are located in Section 4.3.2.2.

During the period 17 July to 11 August 1978, a
visiting experiment was conducted in support of an
existing Atmospheric Characterization program. The
experiment was designed to meet the following four
objectives:

1)   obtain data to characterize the angular
     dependence of seeing;

2)   investigate the short term statistics of
     seeing;

3)   characterize the noise in the AMOS Model II
     Star Sensor; and

4)   process existing data previously collected
     with the Real-Tme Atmospheric Monitor (RTAM).

As part of the AFWL IR Measurement program, another
visiting experiment will be conducted at AMOS during
the months of March, April and May 1980. A Forward
Looking Infrared (FLIR) sensor and an associated adaptive
optics package known as AMOS Breadboard Test System
(ABTS), will be mounted on the rear Blanchard surface
of the 1.6 m Telescope.

The package will be used to demonstrate the acquisition
and tracking of satellites, particularly in the daytime,
and to investigate the capabilities of an infrared
adaptive optics system.

In preparation for this experiment, modifications
are being made to the 1.6 m Telescope and to room 26
of the Observatory which will house the system control
electronics. A six-inch diameter Germanium lens will
be installed in the optical system of the f/16 telescope
to convert it to an afocal system as required by the
FLIR. The requirements for the system control elec-
tronics which will be housed in room 26 are similar to
the demands of the ITEK Compensated Imaging System
which will be installed in this same room in 1980.
The modification schedule for room 26 was accelerated
for this visiting experiment.

3) Compensated Imaging Support

Success of the Compensated Imaging System (CIS)
is of prime importance to the Phase IV Program. When
proven and operational on the 1.6 m Telescope, the
CIS will represent a major technological breakthrough.
This capability will provide, in principle, imagery of
orbital and suborbital objects with an angular resol-
ution approaching the diffraction limit of the systems'
fore-optics. In the case of the AMOS 1.6 m Telescope,

this is about 0.1 arcseconds which represents an order-of-magnitude improvement over the average limit imposed by atmospheric seeing. Perhaps of equal importance is that the CIS will be the first field demonstration of a fully adaptive optical system. Such optics have been considered for a variety of applications; hence, an operational IS will have wide ranging impact.

Current AMOS support to the CIS program includes:

1) site preparation;

2) interfacing with CIS contractors;

3) performance of special measurements and tests to assure compatibility of the new hardware with AMOS and to aid in CIS design decisions; and

4) development of classical imaging and atmospheric data bases to allow performance evaluation and optimization when the CIS hardware arrives on-site in 1980. Significant progress was made in all of these areas during 1978 and 1979.

Vibration tests were conducted on the 1.6 m Telescope to aid Itek in their design of mechanical structures for the CIS telescope-mounted components.

The 1.6 m Telescope was loaded with weight (over 5,000 pounds) to simulate the CIS hardware. The telescope was then tested for step response and

velocity and acceleration performance. These tests
are of critical importance since the telescope-
mounted equipment has increased significantly
in weight as Itek's system design has progressed.
Moments of inertia now exceed those originally specified
for the 1.6 m Telescope. Although performance has not
yet been significantly degraded, concern does exist
and testing will continue in parallel with the design
effort.

By the end of 1979, AMOS engineers - working
with CIS contractors and appropriate subcontractors -
had completed design and installation of the extensive
facilities modifications that are required to support
the CIS system (Section 4.3.3.1). These modifications
included installation of special wiring and air
conditioning systems as well as alterations to existing
buildings.

Major accomplishments in the area normally
defined as classical imaging, i.e., imaging without
adaptive optics, were achieved during and continued
through 1979. To support this program, AMOS engineers
designed and fabricated a versatile sensor package
which was subsequently installed on the side Blanchard
surface of the 1.6 m Telescope. Also, computer-
controlled motion of primary/secondary mirror spacing

(to account for focal plane offsets due to non-infinite target ranges) was implemented on the 1.6 m Telescope. These new hardware capabilities, when combined with the diffraction limited optics of the 1.6 m Telescope and new measurement techniques resulted in excellent resolved images of several near-earth satellites (Section 4.3.3.2).

The atmospherics instrumentation systems that had been developed and evaluated during the Phase III Program were brought to an operational status during 1978. By the end of the year, joint classical imaging/ atmospherics measurements were being conducted. These measurements were continued during 1979 to obtain the required data base for the CIS program.

4) Target State Vectors

During the latter part of Phase III, a program was initiated to determine system performance parameters and hardware necessary to generate improved target state vectors by including laser range data. The goal was to provide a hand-off vector to down-range sensors. This activity included range measurements with the AMOS LBD/Ruby Laser system and development of a model to budget permissible errors, thereby defining necessary improvements. During Phase IV, these improvements are being implemented at AMOS and a real-time hand-off will be demonstrated.

This program is called LBD Phase II and is described in detail in Section 4.9. Some of the important results to date are summarized here.

Laser ranging and angular pointing data obtained at AMOS were reduced and used in conjunction with a model developed by AERL to evaluate measurement error and observation scenario effects on hand-off accuracy. The measurement errors were determined to be about ± 2 arcseconds (one standard deviation) in angles and about ± 2 meters (one standard deviation) in range. Propagated down range, these uncertainties result in a maximum predicted error ellipsoid axis of the order of 30 meters, 3σ, at 90 kilometers (300 kft) target altitude. This resul is well within that required by overall program goals.

The ranging data used in the analysis were obtained on the retro-reflector satellite GEOS-C. The return from this target, using the AMOS Ruby Laser as the transmitter and the 1.6 m Telescope as the receiver, is the order of 10^6 photoelectrons per laser pulse. When the same system is used to range on a 1 m^2 Lambertian-type target at 1600 km range, the return is only a few photoelectrons per laser pulse. Actual hand-off of a typical target of interest, therefore, presents a far more difficult

problem than obtaining an updated state vector on GEOS-C.

In order to accomplish the hand-off demonstration, several upgrades to the laser receiver/detector system have been implemented. This work began in the Summer of 1978 and includes installation of more sensitive detectors on the 1.6 m Telescope along with development of a computer-controlled range gate and a multiple-target ranging receiver. The latter improvement allows low level returns to be processed even in the presence of noise. New software was developed for these new hardware systems. In addition, a major software effort was required to include range in the Kalman filter and to provide the required handoff state vector to the down-range sensor.

By the end of August 1979 all of the above tasks were complete. In addition, a state vector based on an angle-only measurement of WTR Mission GT69 was transmitted to Kwajalein in real-time. This latter effort demonstrated AMOS's new capability to generate and transmit a real-time IRV. The actual demonstration of a real-time hand-off using both angles and laser range is scheduled for 1980.

5) Systems Support and System Testing

Although not as exciting, perhaps, as the measurement and experimental programs discussed

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in the preceding paragraphs, the activities termed

systems support and system testing are no less

important to the accomplishment of overall program

goals. The two categories obviously augment each other.

Problems observed during measurement programs generate

a period of system testing which, in turn, normally

leads to a system improvement that consequently

further increases AMOS measurement capabilities.

Systems support and testing activities are

discussed in detail in Sections 4.1 and 4.2. Two

important examples are:

1) provision of new acquisition telescope systems
   for both of the large telescopes; and

2) development of the computer-controlled auto-
   focus capability referred to previously.

The requirement for more sensitive (+16 m_v against a

dark night sky) and versatile acquisition telescopes

was generated by current and planned measurement

programs. The need for a computer-controlled auto-focus

capability on the 1.6 m Telescope arose from the

stringent requirements of the Classical Imaging effort.

6) Conclusions

The first two years of the AMOS Phase IV Program

have seen significant progress in the areas of measure-

ments, visiting experiments and system development.

Data was obtained during the year that is of great value to various DoD programs. This data has included LWIR and visible radiometric signatures of space objects, high precision metric information (both angles and range) and images that approach the diffraction limit of the 1.6 m Telescope.

Special support was given to outside users in the area of visiting experiments. The state-of-the-art AMOS systems were completely successful in achieving the individual program goals.

In parallel with these measurements and experiments, major improvements were and/or are being implemented in the LWIR, laser, software and test bed systems. As the new capabilities inherent in these improvements become available, AMOS will be able to provide additional measurement support to the DoD community and continue to satisfy the basic program objectives.

4.0 PROGRESS ON PHASE IV TASKS

The following sections discuss, in detail, progress on
specific Phase IV tasks during 1979 and are keyed to the
contract Statement of Work.

Figure 3-5 shows the Work Breakdown Structure (level
three) which is used internally by AERL to monitor the progress
and status of individual tasks.

4.1 Systems Support

The basic requirement of the Systems Support task is
to assure that all existing AMOS systems are operational,
calibrated, and optimized for conduct of measurement and
experimental programs. This task is concerned with areas of
system testing, evaluation and optimization that are not
necessarily covered in a routine manner or by established
procedures as are, for example, system maintenance and periodic
testing. In short, a major goal of this task is to assure the
integrity of all AMOS systems.

A second, equally important, goal of the Systems Support
task is to expand and develop existing AMOS capabilities such
that AMOS can continue to respond to the evolving requirements
of new measurement and experimental programs. This is accom-
plished by conducting tests and performance evaluations on
existing systems, identifying directions for improvement and,
after approval by RADC, implementing these improvements.

Although hardware and software systems are of equal importance from the standpoint of mission success, they require slightly different methods of approach within the context of the Systems Support task and, therefore, are treated separately here.

4.1.1 Hardware Systems Support

As stated above, the Systems Support task involves both the optimization of existing system performance and the development of new capabilities. An excellent example of the latter is the implementation of new AMOS Acquisition Telescope Systems (AATS) for the 1.6 m and 1.2 m mounts. During the past several years, based upon current and planned program requirements, it became clear that the existing AMOS Acquisition Telescopes were not adequate. The 10-inch system on the 1.6 m Telescope had a single 1° field-of-view. The 18.6-inch system on the 1.2 m Telescope mount had only two fields-of-view (3° and 23'). Both systems exhibited a large amount of flexure as a function of attitude and both were inadequate from the standpoint of sensitivity. Under the Teal Amber contract, AERL performed systems analyses to determine the required performance specifications and operational characteristics for the new Acquisition Telescope System. The resultant specifications were based upon both known and anticipated program requirements, and experience

obtained by the AMOS staff over the past several years in
the general area of acquiring and tracking various classes
of manmade space objects. The basic requirements are given
in Table 4-1. Procurement specifications for the telescopes
and their associated TV cameras were prepared and submitted
to appropriate vendors for technical and cost proposals.
Purchase orders were placed with the Boller & Chivens
Division of the Perkin-Elmer Corporation for the telescopes
and with Quantex Corporation for the video systems.

A baseline analysis was subsequently performed which
included investigations of both single and two-telescope
configurations. Based upon consideration of system com-
plexity, performance, technical risk, size and weight, a
two-telescope configuration was selected for the AATS.
The AATS system diagram and optical schematic are shown in
Figures 4-1 and 4-2 respectively. The system includes
a filter wheel, motor-driven secondary mirror, sun shutter,
reticle projectors and associated control electronics and
displays. A remotely controlled motor-driven flip mirror
changes the optical path to the TV camera from the 22-inch
diameter to the 8-inch diameter telescopes. In like manner
a motor-driven, remotely controlled 5X magnifier changes the
22-inch diameter telescope 0.5° FOV to a 0.1° FOV. Optical,
thermal and structural analyses were performed. Of particular

Table 4-1. AATS — basic performance requirements.

System Utilization	Field-of-View	Sensitivity	Background (m_v/sec^2)*
Low orbit, high angular velocity, bright targets	3°	+11	+17.5
High orbit, low angular velocity, dim targets	0.1°	+16 (+17 design goal) +14	+21 +17.5
Precision handoff	0.1°	+16 (+17 design goal) +14	+21 +17.5

*m_v = Apparent Visual Magnitude

10-429A

REAR VIEW

ISIT TV
SENSOR

8-INCH TELESCOPE

RETICLE
PROJECTORS

22-INCH TELESCOPE

SIDE VIEW
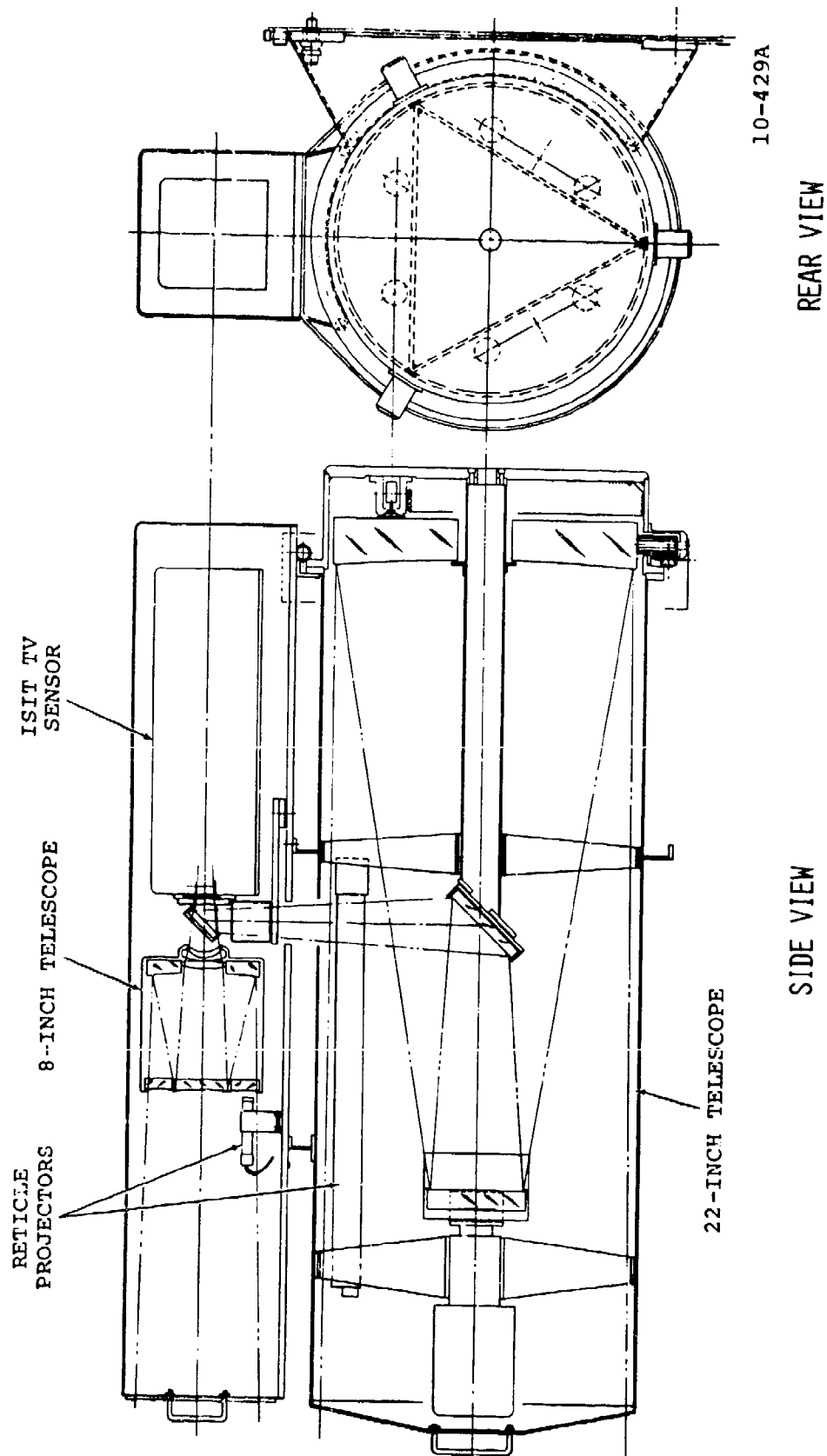
Figure 4-1.   AATS acquisition telescope system.

5X CATADIOPTIC
MAGNIFIER
(0.1° OR 0.5° FOV)

PRIMARY MIRROR
22" DIAMETER, f/3

10-430

FLIP MIRROR
8" OR 22"
TELESCOPE

PRIMARY
MIRROR

FOLD
MIRROR

SECONDARY MIRROR
AND CORRECTOR

SECONDARY MIRROR
6" DIAMETER
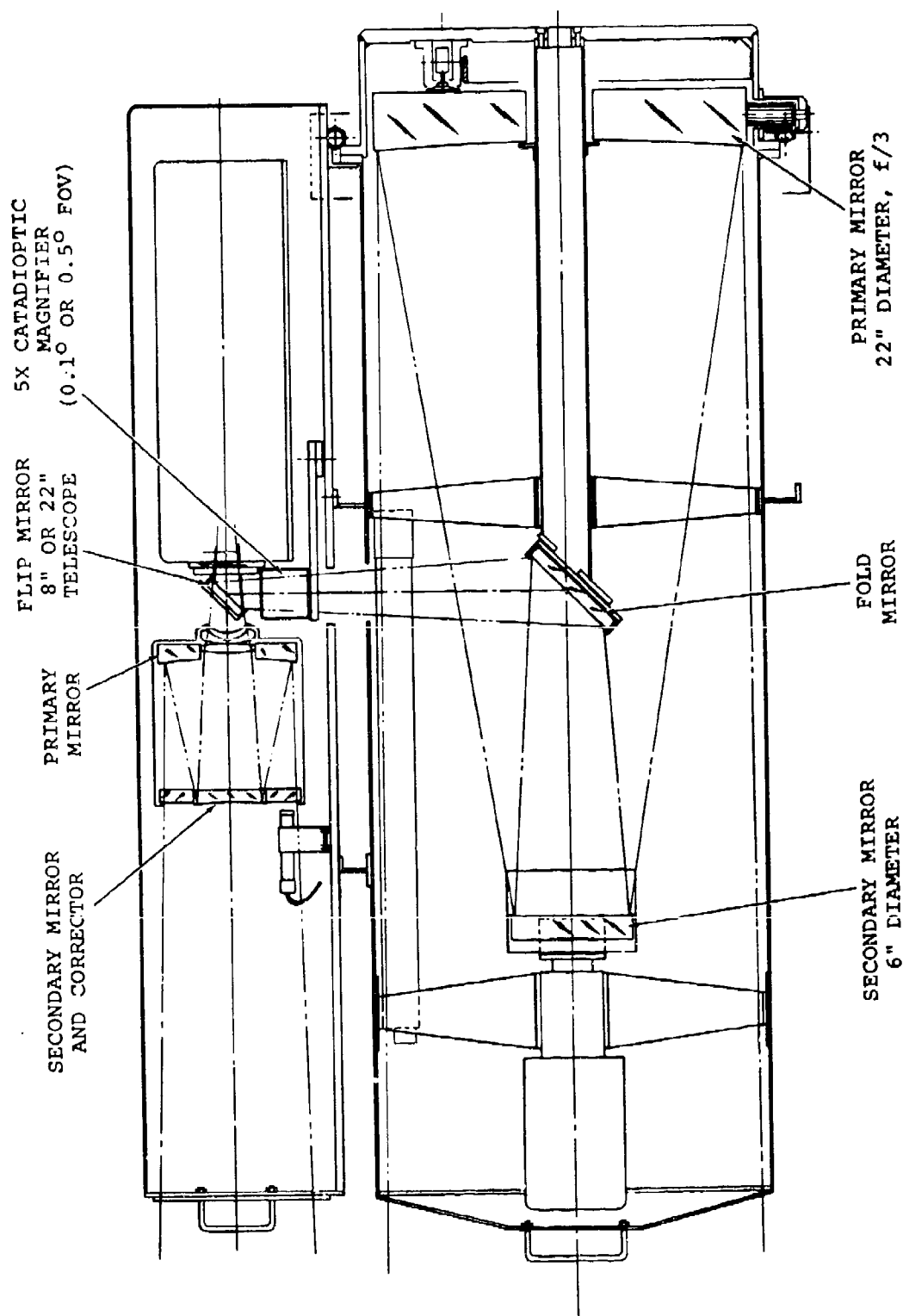
Figure 4-2. AATS optical diagram.

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interest was the result of the encircled energy analysis,
which indicated that the configurations exceeded the specified
requirements, except at the edge of the field for the 0.1° FOV
(illustrated in Table 4-2). The AATS telescope designs
were accepted, parts fabricated and both systems assembled.

Preliminary acceptance testing of the AATS telescopes
began on March 16, 1978 at the Perkin-Elmer Applied Optics
Division (AOD), Costa Mesa, California. Problems developed
at the initiation of the testing. Although the 22-inch
telescope is an all-reflective design, the system produced
an apparent longitudinal chromatic aberration and excessive
scattering in the 0.5° FOV. Efforts to focus the system
for energy concentration measurements produced partial con-
centrations of red and blue separated axially by as much as
0.020 inches but with no zero-order white patch. The nominal
depth of focus for the 0.5° FOV system is $\pm$ 0.003 inches.
Thorough investigations were made of both systems, the test
set-up, and the test equipment. During the testing, the
aperture of the 22-inch diameter telescope was effectively
reduced to 12 inches and the color problem was eliminated.
When the aperture was increased to 16 inches, the color
problem began to reappear. After going through a complete
evaluation, it became evident that the prime candidate for
the color problem was the multilayer, high efficiency,

Table 4-2. AATS encircled energy analysis.

Specification Optical Performance Requirement	Results of Image Quality Analysis
3.0° FOV 85% of the energy within a 65 µm diameter or less across the field	**3.0° FOV** For a 65 µm diameter On axis - 97% of the energy 0.5° - 97% of the energy 1.0° - 97% of the energy 1.5° - 97% of the energy
0.5° FOV 85% of the energy within a 30 µ diameter or less over the central (+0.05°) of the field and 65 µm diameter or less over all other portions	**0.5° FOV** For a 30 µm diameter On axis - 88.9% of the energy 0.1° - 90.4% of the energy For a 65 µm diameter Edge of field - 92% of the energy
0.1° FOV 85% of the energy within a 150 µm diameter across the field	**0.1° FOV** For a 150 µm diameter On axis - greater than 85% of the energy 0.025° - 83% of the energy 0.35° - 85.7% of the energy 0.05° - 82.6% of the energy

dielectrically enhanced mirror coating. Discussions were held
with Liberty Mirror Inc., the coating vendor, as well as with
coating experts across the country. The Liberty Mirror No. 758
coating contained approximately 27 layers and was approximately
4 microns thick. To definitely prove that the coating was the
cause of the color problem, the mirrors were removed from one
of the 22-inch diameter telescopes, the coating stripped off,
the mirror recoated with aluminum without a protective overcoat,
reassembled, aligned, and tested. The color problem was gone
and so was was the excessive scattering.

The next step was the evaluation and selection of a replace-
ment mirror coating. Various vendors were contacted, their
coating characteristics evaluated and finally one developed by
the coating department at Perkin-Elmer, Norwalk, Connecticut
was selected as the replacement. The coating selected consists
of five layers (Al, MgF_2, ZrO_2, SiO_2, ZrO_2) with a total
thickness of 0.4 microns. The primary, secondary and tertiary
mirrors of the 22-inch diameter telescope and the flip mirrors
were stripped and recoated.

Problems of a different nature developed with the 8-inch
diameter (3° FOV) telescopes. The imagery of one telescope was
good on-axis but poor off-axis and the focal plane location was
out of tolerance. The telescope was disassembled and the

optical elements and mechanical parts inspected. All were found
to be within tolerance except for the front corrector. Its
thickness was 0.009 inches out of tolerance, but this condition
could not cause the poor imagery problem. The telescope was
reassembled and carefully aligned. The images were good both
on-axis and off-axis, and the focal plane location was within
0.001 inches of the theoretical value. The assembly was then
potted for final installation in one of the AATS.

Following this assembly, the optical systems were
transported from Perkin-Elmer, Costa Mesa, California to
Boller & Chivens, Pasadena, California, some 30 miles away. In
the course of this transportation, one of the 8-inch systems
was mysteriously lost and to this date has not been replaced.

Assembly of both AATS was completed (less one 8-inch system)
and final precision alignment of the AATS for the 1.2 m Telescope
initiated. A problem developed during the alignment activities.
Astigmatism was observed which appeared to be caused by a
pinched mirror in the optical train. Both flat mirror assemblies
(mirrors and mounting plates) were removed, tested interfero-
metrically, and found to be okay. Further testing of the
primary and secondary and its mount were satisfactory and
showed that the problem was in the primary mirror ass mbly.

The factory acceptance testing was concluded at Boller & Chivens, South Pasadena during the week of March 26 thru 30 1979. Although measured optical throughput and percentage of encircled energy measurements fell somewhat short of expectations, the units were accepted for delivery to Maui. Briefly the test results were as follows:

	Spec. Req.	1.2 m AATS	1.6 m AATS
Encircled energy:			
3° FOV on-axis	85% in 65μ	--	92.6%
0.5° FOV on-axis	85% in 30μ	67.4%	68.2%
0.5° FOV edge of field	85% in 65μ	81% avg	86% avg
0.1° FOV on-axis	85% in 150μ	62%	59.9%
0.1° FOV edge of field	85% in 150μ	58.7%	56%
Throughput:			
3° FOV	65%	--	52.5%
0.5° FOV	60%	66%	68.6%
0.1° FOV	45%	42.6%	45%

The coincidence of the focal points of the three FOV's and their axial alignment were well within specifications. All of the electro-mechanical test results were acceptable.

The acquisition telescopes were received on Maui on
30 April 1979, after a long delay due to a backlog of other
air freight shipments caused by a United Air Line strike.
The systems were independently set-up and bench aligned before
installation on their respective telescopes.

The first unit was mounted on the 1.2 m Telescope in
June following a refurbishment of this mount which included
recoating of the 1.2 m primary mirrors. The completed unit
was tested, and found to meet performance specifications and
transitioned to ADCOM in late July 1979.

Mounting of the second AATS on the 1.6 m Telescope was
delayed, in part, by the MEV experiment and other high priority
work until October and became fully operational in December
1979 when the 3° field-of-view subsystem, which had been on
loan to MOTIF, was re-installed in this second unit.

The AATS Television Sensor System consists of the camera
head (mounted in the AATS), a camera control unit (CCU) and
the Quantex DS-20 Digital Image Memory/Processor. The camera
head, which is a modified Quantex QX-12 camera, contains a
40 mm Varo 8605/1 Image Intensifier fiber-optically coupled
to a 40 mm RCA C-21202 SIT tube, two high voltage multipliers,
a preamplifier, deflection amplifiers and voltage regulators.
There is also a motor-driven mechanical focus assembly which
can move the image intensifier/tube combination $\pm$ 0.64 cm.

The camera control unit performs the video processing and video control functions. All of the controls other than the mechanical focus are located in the DS-20 unit. Five DS-20 controls that effect the camera operation are video gain, sensor gain, beam, focus and integration time. The mechanical focus controls are located on the CCU front panel. The DS-20 Digital Image Memory/Processor is used for image capture, image processing and display tasks. It uses an A/D converter, a random access memory and an arithmetic unit, all under microprocessor control, to perform digital video processing functions in real-time. It has a 512 x 512 memory and an A/D converter sampling rate of 10 MHz with a resolution of 6 bits.

The two TV camera systems and spare sensor assembly (potted image intensifier/SIT tube combination) were acceptance tested and delivered to AMOS in late 1978.

The two TV systems were installed in their respective acquisition telescopes in June and December of 1979 bringing the AATS units to full operational capability (with the exception of the missing 3° FOV on the 1.2 m mount).

In late 1979, following a decision not to replace the missing 3° optical system with an identical Perkin-Elmer unit, AMOS personnel began looking into several less expensive alternatives. These alternatives ranged from simple single lens refractors to the more complex catadioptic systems which

approach the performance of the original unit. Studies reflecting the trade-offs of the alternatives are currently underway and a specific recommendation for a replacement will be made in 1980.

4.1.2   Software Systems Support

Successful accomplishment of Phase IV tasks requires the use of existing computer software. If, however, a special performance evaluation is undertaken, and data reduction and analysis can be expedited by use of the computer, then the Software Systems Support task is utilized to formulate a new code to produce the desired results.

During 1979, for example, modifications to the AMTA data reduction software were implemented to provide the capability of handling data recorded prior to the addition of the AMTA LTI hardware and the subsequent procedural changes in data taking and calibration. These changes were necessitated as a result of the requirement to validate data obtained in 1975 which will subsequently be reduced at Everett.

In addition, program RADD (received from Everett) has been modified to make it compatible with the MODCOMP II computer format. Program RADD calculates radiant exitance, bandwidth, and effective band location for the AMTA (or any other) radiation sensor as a function of temperature. The program has the

option of inputting response functions defining object and
atmospheric spectral characteristics. The program will be
utilized in on-site data reduction and validation.

Other support tasks included a modification to the
telescope control software to provide the ability to step
the telescope in increments as fine as 0.5 arcseconds. This
capability was required for accurate pointing of narrow beam
lasers at synchronous satellites.

Toward the end of the year the software capability of
the ERG report generator were being expanded to handle cases
involving trajectory and encoder historys of multiple mount
operations.

4.2   System Testing

AERL conducted tests on the AMOS subsystems during 1979 to
assure that they continued to have the performance capabilities
required to support research and development programs. This
testing falls into two general categories - periodic and repair/
replacement - which are discussed below.

4.2.1   Periodic Testing

Periodic testing and performance evaluation of existing
equipments may occur in various ways. In the case of equipment
which is in regular operation in the acquisition of data or in
regular operating support of that equipment, the monitoring

of data quality or of other evidences of system performance (e.g., pointing accuracy or image quality of a telescope) will give a running indication of the condition of the system in general and provide clues as to a specific area or component requiring attention. Baseline performance has been established for all major AMOS systems and related support equipments and, therefore, they are evaluated against their respective baselines.

Periodic tests of system performance are required for two primary reasons. First, anomalous system behavior will be uncovered by a review of data (e.g., pointing drift as a function of time or temperature). When problems are dis-covered, tests are conducted, and the analyzed data used to determine a remedial course of action. Secondly, certain tests are required to evaluate potential interface problems which are not specifically identified with a particular visiting experiment or special program.

Additional special testing would center on the many equipments and components (mostly optical) which are used in experimental applications and instrument packages, the quality and performance potential of which are not completely known. Precise calibration and evaluation of these components will significantly increase their value to the Observatory.

Data obtained as a result of periodic tests is used to update maintenance schedules and test procedures.

4.2.2 Repair/Replacement Testing

Upon repair and/or replacement of operating elements in the basic AMOS systems and related equipment, AERL performs testing and evaluation to ensure that proper operation has been restored. Upon successful conclusion of the testing, the system is then certified for use in obtaining valid and reducible data.

A specific example of this category of testing is the replacement of the defective 1.6 m Telescope azimuth drive motor. The replacement effort required a specific engineering approach to be developed. The motor was originally installed prior to mount assembly but required replacement without the major cost and time impact that mount disassembly would have entailed. Following replacement, detailed testing was performed before the 1.6 m Telescope system could again be placed in an operational status.

It is important to point out that, in all but the most trivial cases, repair-replacement testing involves significant effort and participation by senior AMOS personnel. In the case of the defective torque motor for example, it is not enough to merely replace the motor and show that the mount can move in azimuth. An extensive test program is required to assure that the overall performance of the 1.6 m Telescope complex has not been degraded.

4.3   Program Support

Program support includes Measurement Programs, Visiting
Experiments, Large System Tests and the Laser Beam Director
Program. The first two categories represent exploitation
of inherent AMOS capabilities, developed over previous years,
to support various DoD programs. The third represents imple-
mentation and evaluation of new DARPA-sponsored technologies
at AMOS. The fourth is concerned with improvements of existing
AMOS hardware and software to fulfill specific DoD requirements.

4.3.1   Measurement Programs

The measurement programs utilize existing or slightly
modified AMOS systems and instrumentation to obtain data
requested by government agencies. Most of these programs were
not specifically identified at the initiation of the current
. contract but evolved during the course of activity as a result
of direct contact with their sponsoring agencies. Measurement
programs are conducted by resident AMOS staff members in
contrast with visiting experiments which involve user personnel
in the role of Principal Investigator. Measurement programs
which utilize existing AMOS hardware systems in a more or less
routine manner and are covered by a. existing Mission Instruction
and Operation Plan (MIOP) are directly assigned to the Operations
Crew who then proceed to obtain the required data in accordance
with the weekly schedule. The data, along with relevant

calibration and system configuration information, becomes a
formal AMOS Data Package which is qualified and, upon direction
of DARPA/RADC, transmitted to the user agency. Measurement
programs which require modifications to AMOS systems and/or
procedures to accomplish their goals are assigned to an AMOS
Principal Investigator for implementation. He is responsible
for preparing a MIOP (CDRL 002), assuring that the modifications
are implemented in accordance with schedules and priorities,
and serves as Test Director during the actual conduct of the
measurements. After qualifying the data package and verifying
that it does indeed satisfy the program requirements, he, after
receiving necessary approvals, transmits the data to the user.
As required, other outputs of Measurement Program activities
include Flash Reports (CDRL 019) and Quick Look Reports
(CDRL 011).

During 1979, AMOS was involved in two significant
measurement programs:

    1)   HAVE LENT IV; and

    2)   AFWL IR Measurement Program.

4.3.1.1   HAVE LENT IV

The HAVE LENT IV Program at AMOS was initiated in
1978 through a series of planning meetings and written communi-
cations with SAMSO and MIT/Lincoln Laboratory. The program
was to consist of two Sergeant-Hydac sounding rocket flights

launched from the Kauai Test Facility, Barking Sands, Kauai, Hawaii. The two flights, scheduled for the morning terminator, were to be launched one week apart. AMOS participation in the measurements involved a three mount operation utilizing AMTA, the CMP, the LBD and ruby laser, the 1.6 m CSP photometer and associated TV systems.

1) Mission Description

The purpose of the HAVE LENT IV Program was to obtain both visible and LWIR signature data and growth rate data on four individual targets. Each of the sounding rockets was to eject two targets. One target, an aerosol cloud (consisting of small silver-coated glass spheres), contained a one meter diameter emissive balloon. The second target was an empty aerosol cloud. The balloon was to be inflated after the surrounding aerosol was dispensed. Primary emphasis, and a requirement for AMOS, was to obtain two color (filter 5 & 6) LWIR AMTA data and visible CMP radiometric data. As part of this measurement the TV images associated with AMTA and the 1.2 m Acquisition Telescope were to be recorded to provide visual growth rate information. A secondary measurement involved the ruby laser system and was to obtain laser scattering and profile measurements on the aerosol clouds and

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to additionally use the photometer receiver on the
1.6 m telescope to obtain cross sectional scans of the
clouds.

Figure 4-3 shows the original predicted
flight path and impact location for the two stage
rocket flights. The azimuth angles with respect to
AMOS were to start at 292.5° and end at 322.8°.
Culmination was to occur at 380 seconds TALO at which
time the vehicle was to be at an altitude of 1800 K
feet and 45° elevation. A detailed listing of the
projected trajectory, with state vectors at 10 second
increments was provided to AMOS by Palo Verde Labor-
atories. The trajectory became ballistic after
burnout of the Hydac stage at 49 seconds after launch.
The state vector 50 seconds after launch was given as
follows:

TIME	AZMTH	ELEV	SLNT RNG
50 sec	294.95°	6.71°	1323.3 K ft.

VEH X	VEH Y	VEH Z
-1200./15 K ft.	535.59 K ft.	154.67 K ft.

X DOT	Y DOT	Z DOT
-642.25 fps	2267.26 fps	9905.09 fps

NORTH

STAGE II

RANGE . . . . 204 NM

AZIMUTH . . . 355 DEG

3σ DISPERSION

  75 NM RADIUS

STAGE I

RANGE . . . 58 NM

AZIMUTH . . 358 DEG

3σ DISPERSION

 ± 20 NM CROSS

 ± 25 NM DOWN

322°

292°

KAUAI

KTF LAUNCH

 AZIMUTH . . . . 0 DEG

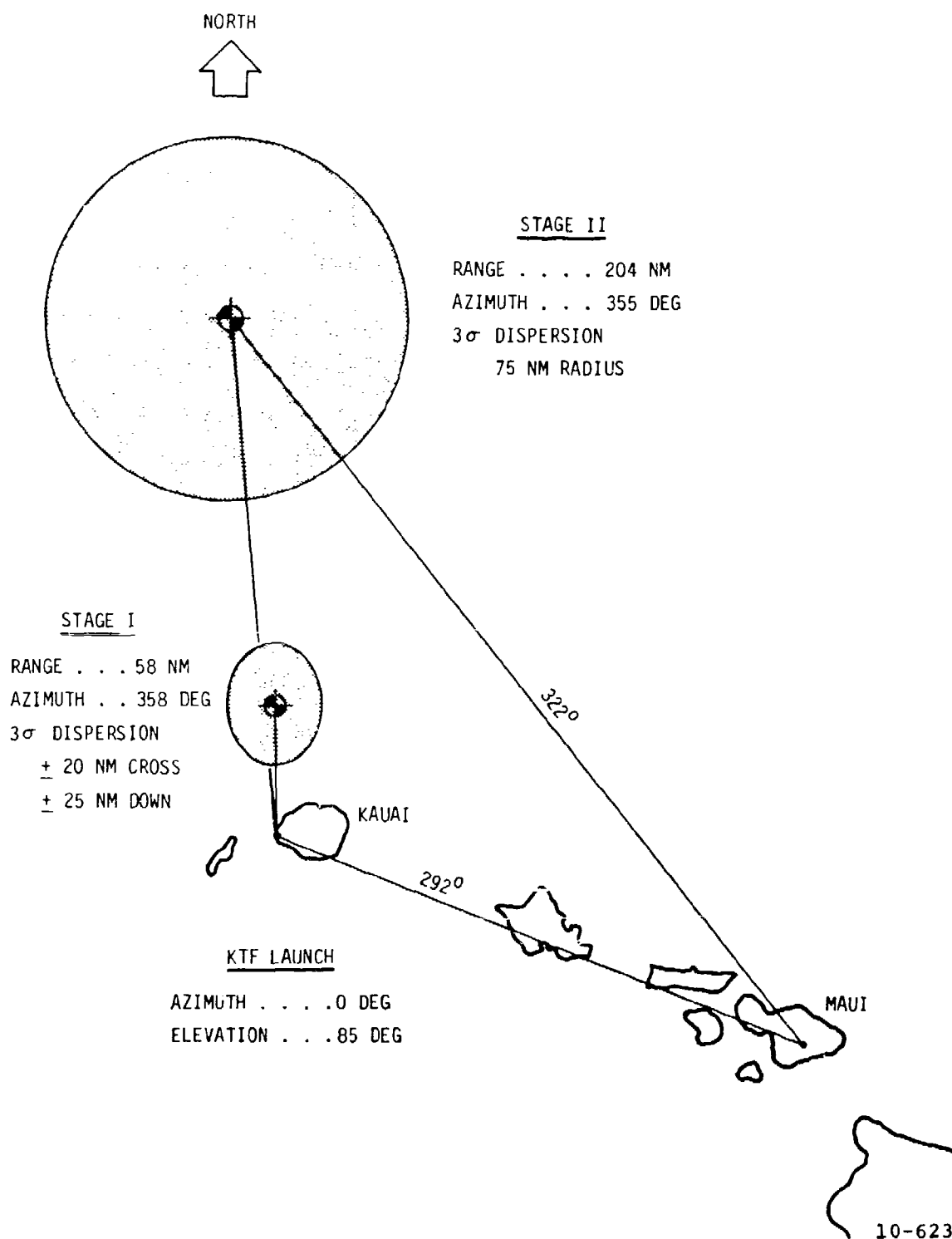 ELEVATION . . . 85 DEG

MAUI

10-623

Figure 4-3. HAVE LENT IV flight path and impact locations.

The launch time was selected to provide AMOS
with a dark sky background but with full solar
illumination at the vehicle height just prior to
ejection of the first dispenser. To achieve these
illumination objectives, the launch time had to be
between 5:15 a.m. and 5:35 a.m. local time during the
selected launch period (the last week of September 1979).

Initial acquisition data was to be provided to
AMOS via the Kokee Park AN/FPS-16 and the Kaena Point
AN/FPQ-14 radars. Upon acquisition, the vehicle would
then be centered in the AMTA/CMP FOV using the AMTA
sensor and visible boresight TV systems. AMOS LWIR
and photometric measurements would then commence at
T+160 seconds when dispensing of the first cloud was
initiated.

2) First Launch

After a one-day postponement due to adverse weather
(high cirrus clouds), the first HAVE LENT IV vehicle
was launched from Barking Sands, Kauai at 5:34 a.m. on
Thursday, September 27, 1979.

The launched vehicle failed to stay within the
three sigma bounds of the predicted trajectory. The
actual azimuth was reported to be 72 degrees East of
the desired trajectory. Two reports were received at

AMOS regarding the failure. The first report indicated
that the failure to achieve the desired trajectory
might have been the result of using a launch rail with
a shorter than normal length. A four-foot launch rail
was used, whereas previous Sergeant-Hydac rocket
flights have used eleven-foot long launchers. It is
possible that the slow burning Sergeant motor did not
achieve sufficient velocity at the end of the rail to
provide adequate aerodynamic control of the vehicle.
It was also reported that subsequent to the launch, a
small amount of side play was discovered within the
rail structure. The high elevation angle (85°) of the
launcher also aggravated the problem.

It was reported that the AN/FPS-16 radar at Kokee
Park lost track at T+82 seconds when the rocket went
directly overhead and that reacquisition did not occur
until T+216 seconds. In addition, it appears that no
tracking data was transmitted to the AMOS site. The
AN/FPQ-14 radar lost track at T+79 seconds and did not
reacquire. AMOS did receive AN/FPQ-14 radar data from
T+9 to T+79 seconds. The rocket did not become sun
illuminated until T+110 seconds and was not acquired
with either the 1.2 m or 1.6 m Telescopes.

The vehicle did dispense the two aerosol clouds
as programmed and the on board TV sensor did transmit
the desired data. The first cloud was observed by the
AMOS dome operators but the control console operators
were unable to locate it with the 3° and 1° field-of-
view Acquisition Telescopes. In any event, AMOS did
not successfully acquire the vehicle and no measure-
ments of the aerosol clouds were taken from this site.

3) AMOS Tracking Trajectories

An ERG (EROS Report Generator) encoder report
was made from the AMOS computer history tape of the
HAVE LENT IV mission. Actual telescope pointing
azimuth and elevation angles taken from the report
have been plotted and are shown as Figure 4-4.
Included in the plots are the operator selected target
inputs. Target 1 is the state vector generated from
the nominal trajectory. Target 2 is the same nominal
trajectory modified by inputs from the AN/FPQ-14
radar. Target 3 is modified by AN/FPS-16 inputs.
Also shown in Figure 4-5 is the nominal trajectory
from which the original pointing angles are derived
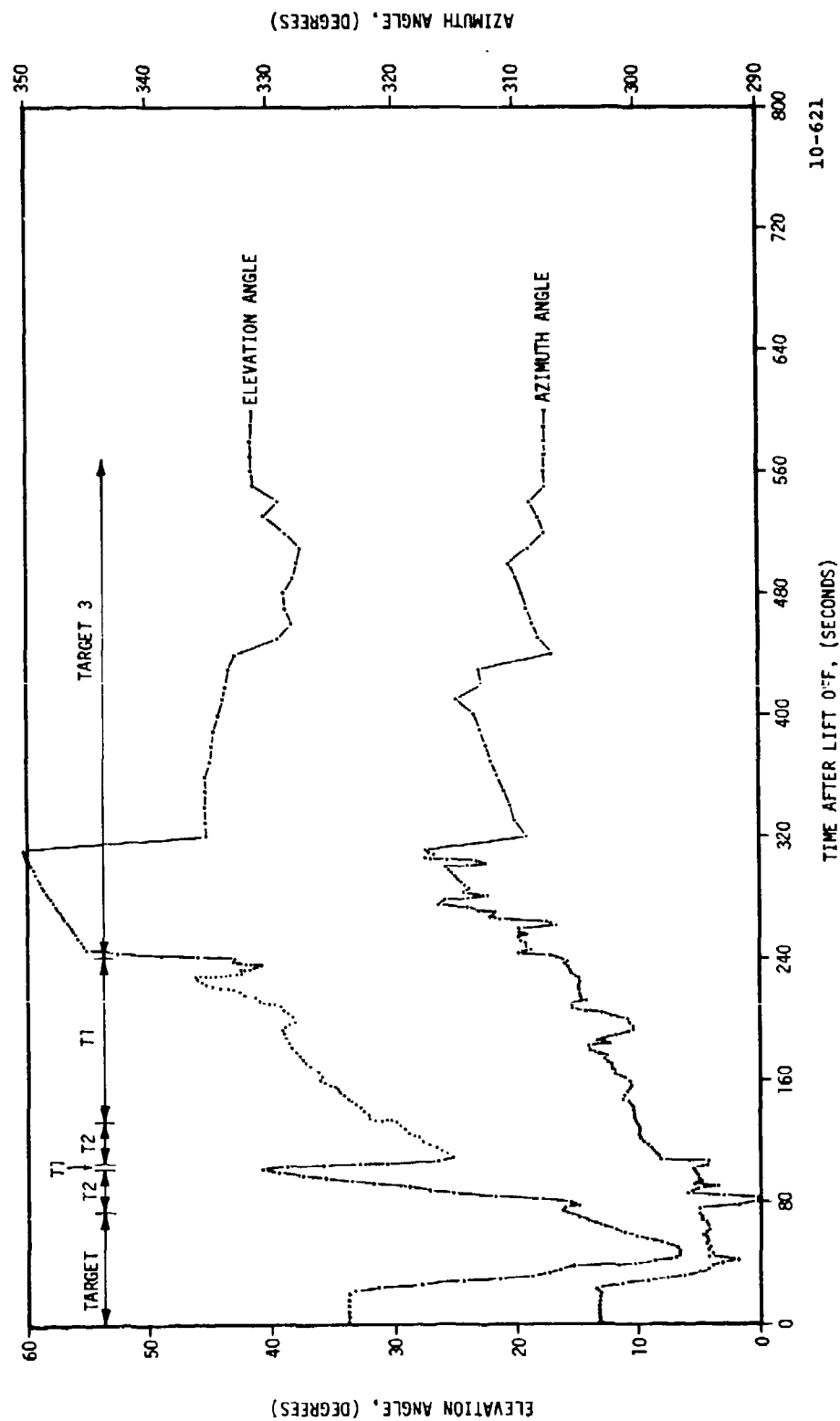(before operator or radar updates).

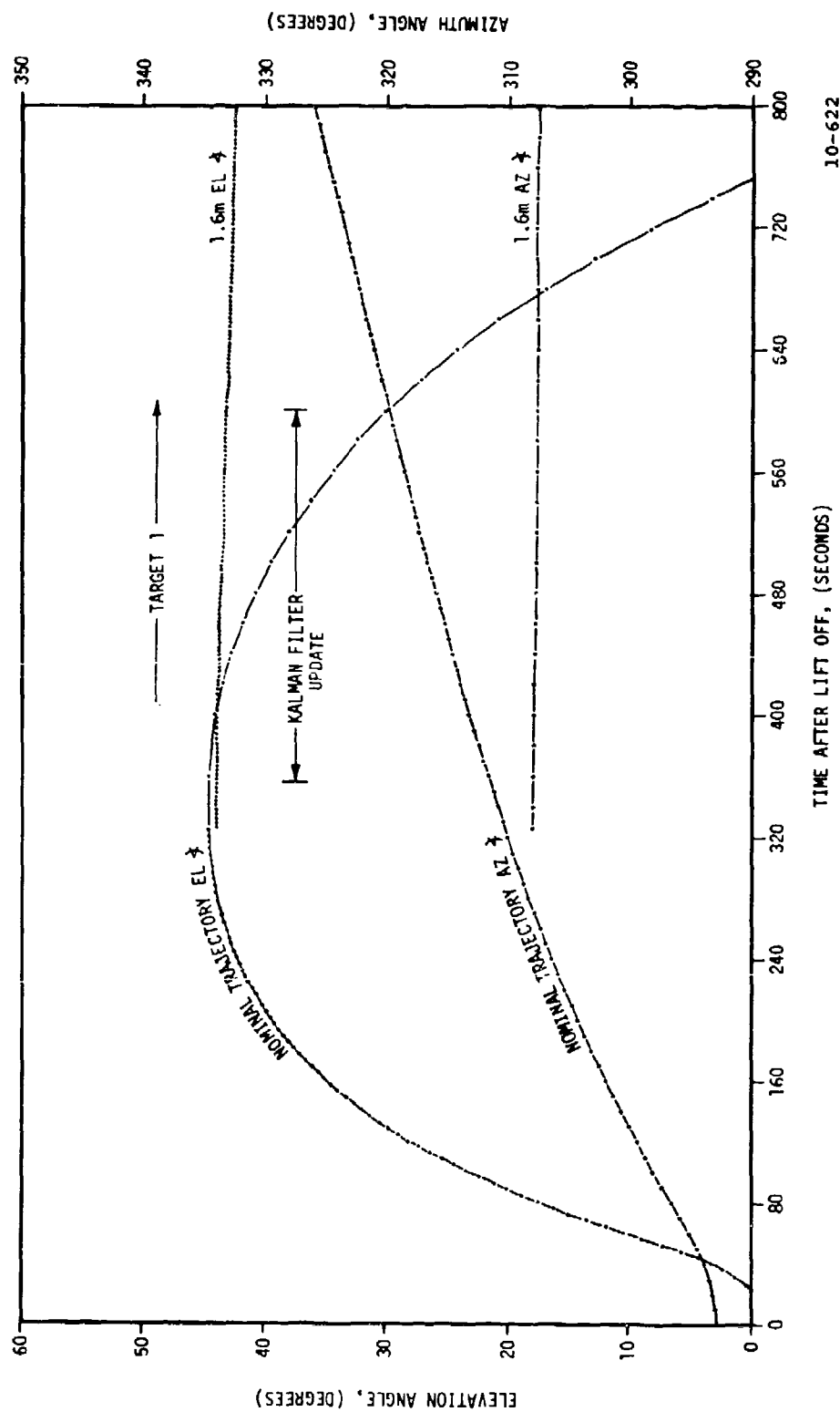Figure 4-4. Actual 1.2m telescope pointing, HAVE LENT IV.

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Figure 4-5. Actual 1.6m telescope pointing, HAVE LENT IV.

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Figure 4-4 shows the pointing angles of the
1.2 m Telescope which carries the AMTA sensor. During
the first 20 seconds after launch, when the target was
below the AMOS horizon, the telescope was pointing at
an elevation angle of approximately 34° evaluating the
infrared background conditions. The telescope was
stepped back to the nominal trajectory at T+44 seconds
and maintained this track until the operator switched
to the AN/FPQ-14 radar at T+76 seconds in an effort to
locate the target. At this point (T+80) radar inputs
were far from the nominal trajectory and the operator
switched back to Target 1 for a brief period to elimi-
nate accumulated off-sets and then back to Target 2
and again followed close to the nominal track in
both Target 2 and Target 1 with added operator induced
off-sets in an attempt to acquire the target which
became sunlit by T+110 seconds. At T+240 seconds the
operator switched to the AN/FPS-16 radar which had
accumulated large off-sets, taking the telescope to 55°
elevation. All off-sets were removed at T+320 seconds
and the telescope continued on the nominal trajectory
until T+440 seconds. Operator induced search off-sets
about the nominal trajectory failed to acquire the
aerosol targets.

Figure 4-5 shows a plot of the original nominal trajectory and the actual pointing angles for the 1.6 m Telescope after T+325 seconds. Pointing angles for the 1.6 m Telescope prior to this time have not been recovered from the history tape. The operator of this telescope observed a bright star in his 1° field-of-view Acquisition Telescope which he believed was one of the aerosol clouds. He centered the star in the boresight and took a number of computer interrupts which updated the nominal trajectory through the Kalman filter and the 1.6 m Telescope went into a sidereal track rate for the remainder of the mission.

4) Second Launch

Because of the difficulties encountered in this first flight and the requirement to analyze data from the radars, AMOS and the on board sensors, the second HAVE LENT IV mission was postponed from the scheduled October 2 launch date. This second launch is now scheduled for April 15, 1980. Lunar illumination conditions are favorable during this latter half of April. Launch delays due to weather or mechanical problems will be incremented on a daily basis. The launch elevation angle for this second flight will be lowered to approximately 82° to stabilize the azimuth trajectory. Prior to the second launch, a Cohu I-SIT

TV camera will be mounted on the side of the 1.6 m
Telescope to augment the 3° FOV AATS. The Cohu camera
incorporates a 30 to 300 millimeter remote controlled
zoom lens which will provide a field-of-view which is
as wide as 30°.

4.3.1.2 AFWL IR Measurement Program

The AFWL IR Measurement Program was initiated in November
of 1978 as a result of several meetings between AERL and AFWL
at both AMOS and the Air Force Weapons Laboratory, Kirtland
AFB. The capabilities of AMOS, particularly of AMTA and the
1.6 m Telescope, are being used to fulfill some of the objec-
tives of the program.

AMOS contributions to the program include a series of sky
radiant granularity measurements, sky radiance measurements and
satellite signature measurements. The objectives and measurement
descriptions for those sub-programs are identified in three AMOS
MIOPs numbered 28, 29 and 32 respectively. As part of the satel-
lite signatures, acquisition offsets were measured on a number
of targets. This data has been used to define search para-
meters for a microprocessor - controlled modification to AMTA
which will result in an automatic search and track capability.

Also as part of the program, the AFWL will provide a com-
plete IR sensor package for test on the 1.6 m Telescope. This
particular portion of the experiment will be performed under

the Visiting Experiments Program and is discussed further in
Section 4.3.2.3.

1) Sky Radiant Granularity Measurements

Sky radiance structure data obtained in January
1979 was calibrated and analyzed with view to identify-
ing phenomena which might impact the Air Force Weapons
Lab experiments to be conducted at AMOS. AFWL will
bring, to the 1.6 m Telescope, an LWIR sensor designed
to measure, and demonstrate the possibility of correcting
for, large atmospheric refractive structure. The
December/January radiance data was gathered to deter-
mine the impact of thermal structure, clear air eddies
and also cirrus clouds, upon the performance of the
AFWL/FACC sensor.

Cirrus cloud affected noise is shown in
Figure 4-6. The 1.2 m, B29 Telescope with AMTA
was stationary with line-of-sight directed toward
zenith and with filter #5 (8 to 13.3 μm) in place.
Wind driven thermal structure drifting across the LOS
produced a noise-like signal which was analyzed. The
plots in the figure were calculated from detector
output voltage histories recorded during the observation.
Nine contiguous twenty second histories were each
transformed to frequency space and averaged together
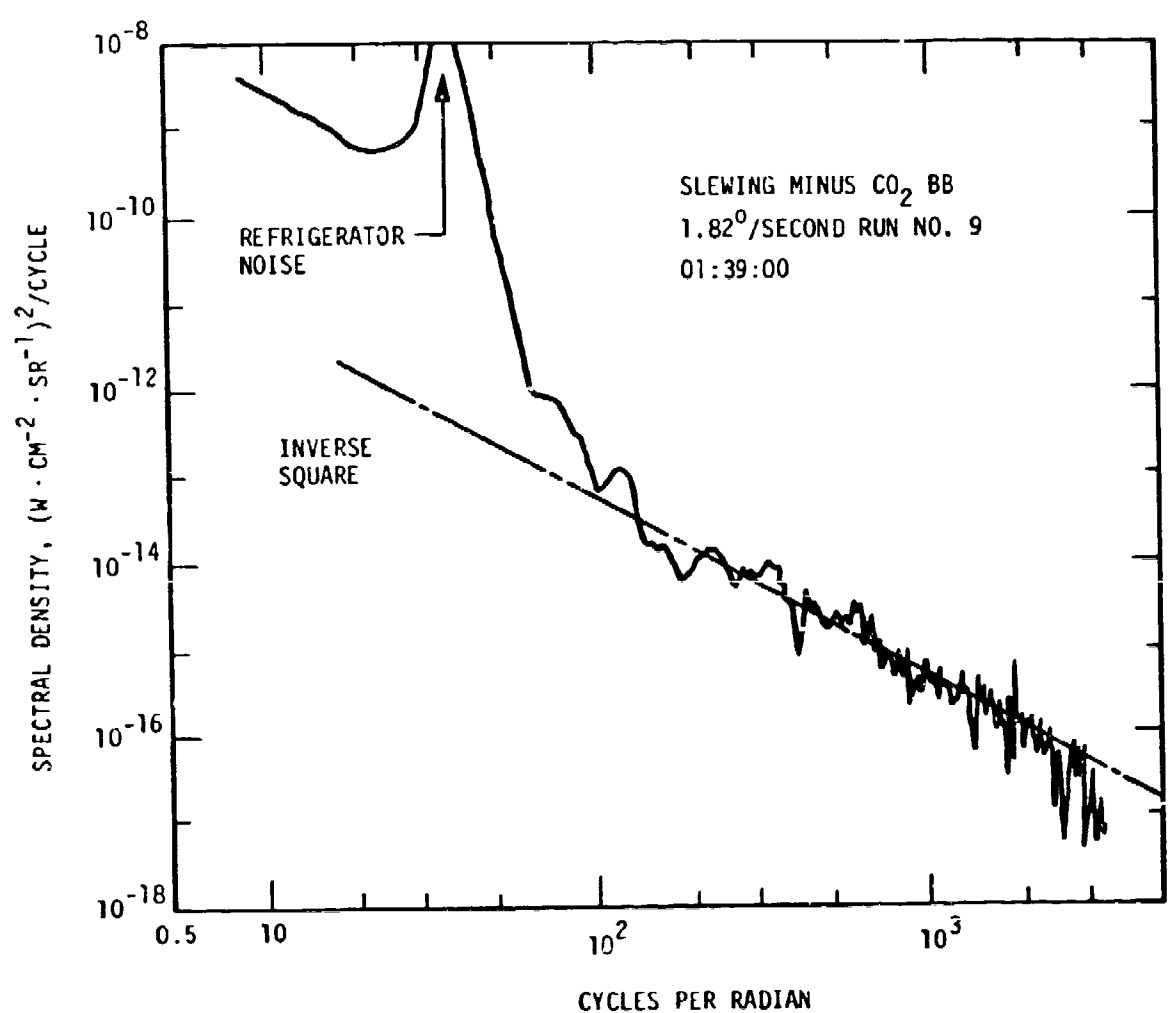for the upper curve and again for the lower curve

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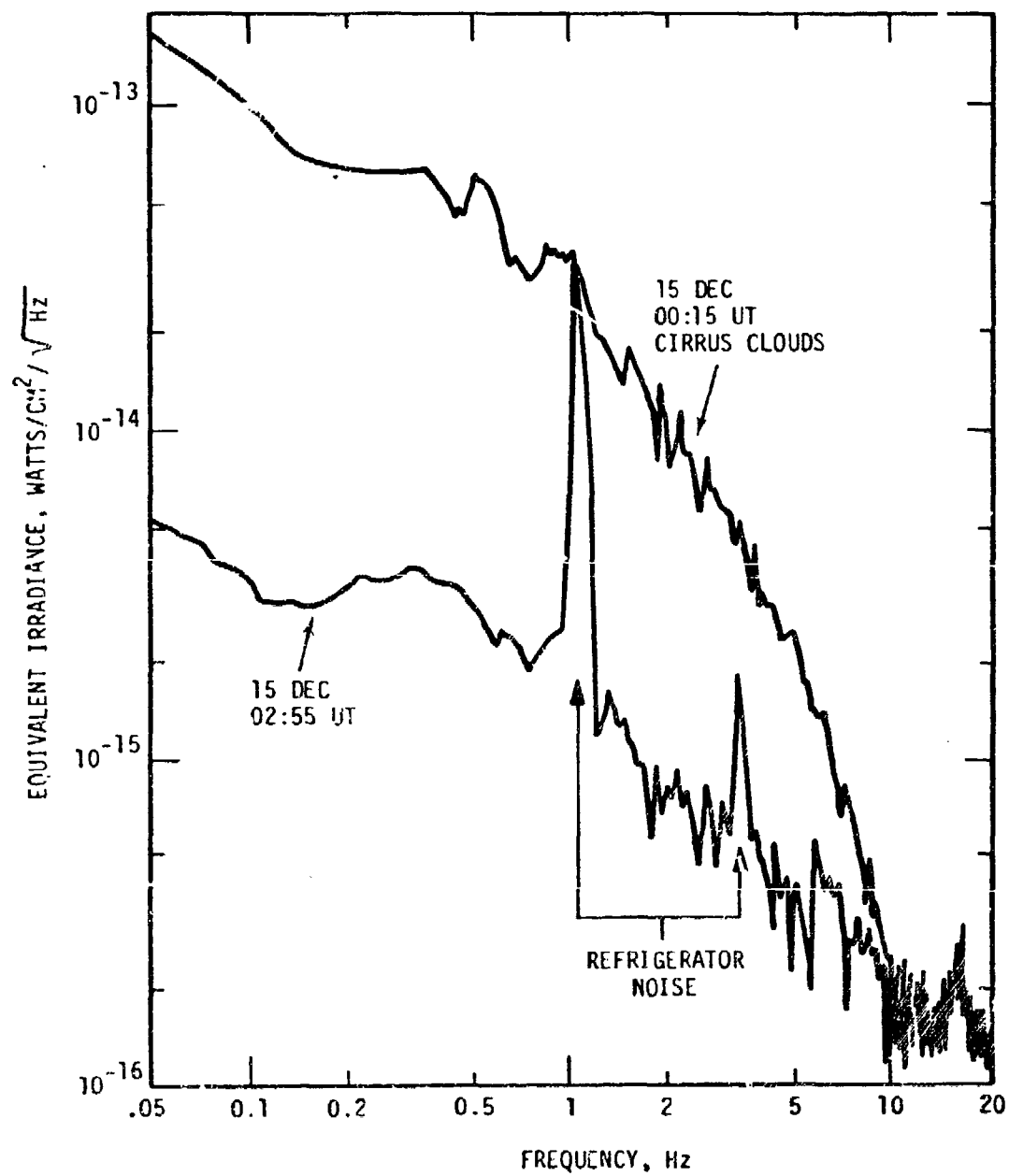
Figure 4-6.   Cloud noise spectrum.

10-628

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(no visible clouds) to produce spectral distribution
functions. Similar functions, obtained by placing a
dry ice chilled blackbody before the sensor, were
subtracted in frequency registration from the sky
results to compensate for amplifier 1/f excess. (In
the 10 μm window a solid CO_2 blackbody has approx-
imately the same radiance as zenith sky, --- but
without moving features). Voltage functions were
transformed to equivalent entrance aperture irradiance
by means of system responsivity values obtained
previously in support of satellite measurements.

The data collected about 2:00 p.m. and 4:00 p.m.
local time shows that the presence of cirrus clouds
degrades the sensitivity of an 8-13 m sensor by
about a factor of twenty at one Hz, but appears to
have little effect at high (>10 Hz) frequencies.
The spikes in the lower plot at 1 and 3 Hz are due
to refrigerator tremors.

A Wiener spectrum produced from low elevation
azimuth slewing data is shown in Figure 4-7. For
structure smaller than half a degree the power spectral
density is seen to follow predictions (i.e., the
inverse square of spatial frequency). Figure 4-8
results from low elevation data obtained 4 January and

Figure 4-7. Wiener spectrum.

10-631

STRUCTURE SCALE, RADIANS/CYCLE

FILTER NO. 5, DETECTOR NO. 22
1.82^0/SEC; AZM SLEW AT $3^0 35'$EL.
3^m SLEW MINUS 3^m STARE SPECTRUM

SPATIAL FREQUENCY, CYCLES/RADIAN

NEFD, WATTS - CM^{-2}
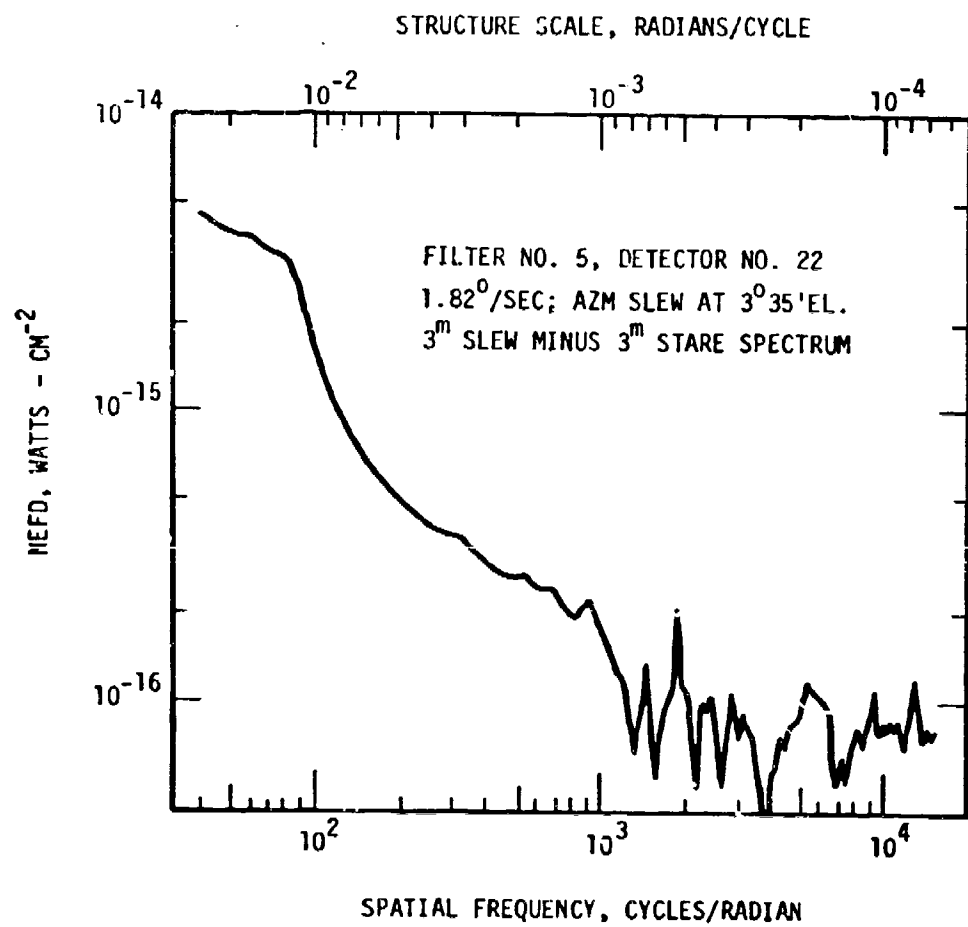
10-627

Figure 4-8.   Power spectral density.

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is plotted in terms of noise equivalent entrance flux density. On this day structure smaller than one millradian did not appreciably alter the sensitivity of the sensor.

The noise data collected is probably representative of average winter conditions at Haleakala. The accuracy and precision of results presented are constrained by blackbody calibration procedure uncertainties and the smooth sky limited sensitivity of AMTA, respectively. Blackbody calibrations were not obtained the day atmospheric data was gathered, so a $\pm 11\%$ uncertainty applies.

There is no evidence that clear air thermal structures will consistently and seriously degrade the performance of an 8-13 μm tracker which has a one-sigma threshold (NEFD) of 10^{-16} watts $-$ cm $^{-2}$ $-$ Hz$^{-1/2}$ or greate at elevation angles above 15°. Occasionally, low elevation thermal structure subtending one to two milliradians (the FACC/AFWL tracker has a 1.2 by 1.6 mr field-of-view) will degrade performance predictions, based upon smooth sky estimates, by a factor of eight (Fig. 4-9). This can be circumvented by:

1) avoiding low elevation exercises;
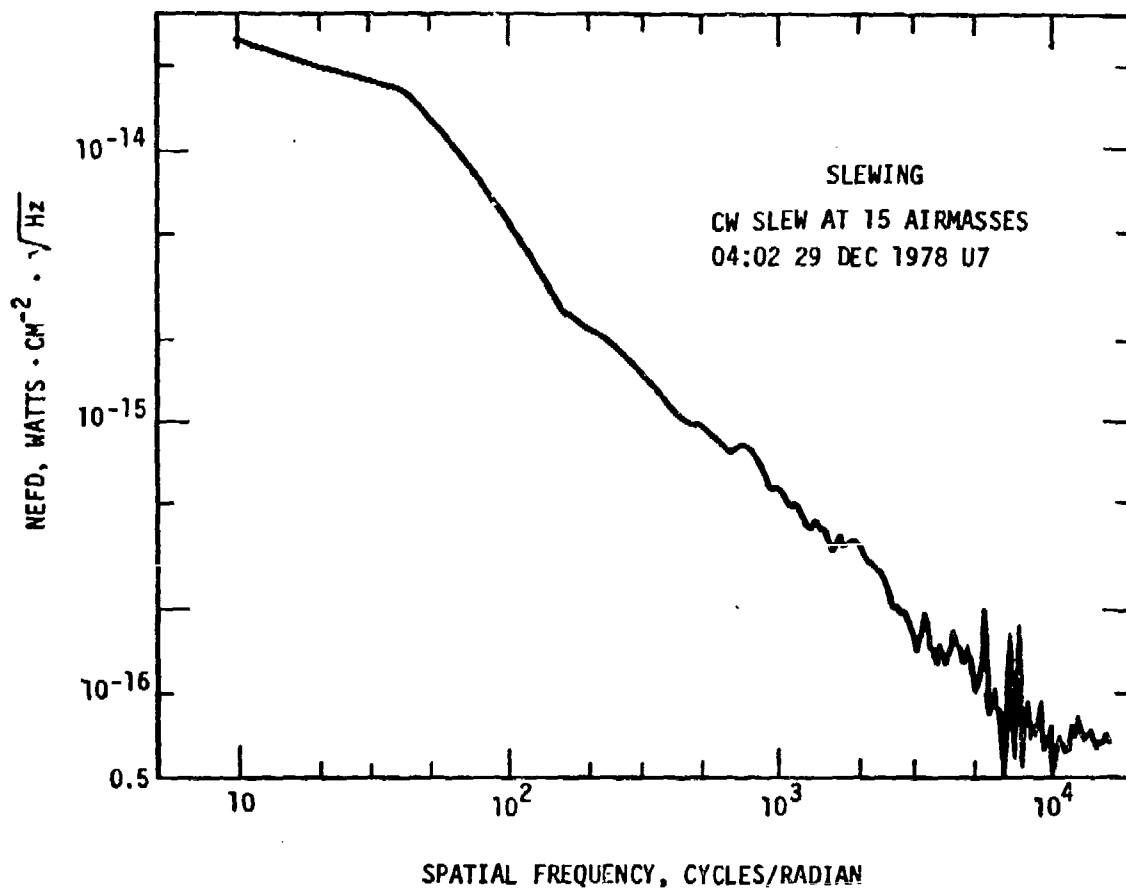
10-649

Figure 4-9.   Radiant granularity.

2)   restricting operation to astronomical twilight
     or full daylight conditions;

3)   high pass filtering the video to improve small-
     target contrast.

This data also shows the temporal correlation scale
ranges between a few seconds and a few tens of milli-
seconds (Fig. 4-6). In fact, granularity effects
beyond 100 Hz have never been observed with AMTA.
Thus, a tracker operating at video frame rates will
freeze atmospheric structure. However, with a current
satellite ephemeris, tracking velocities will be
reasonably correct; therefore, a modest amount of
integration (five to ten video fields) will wash out
the structured foreground to reveal 'stationary'
targets. The existing internal time-delay-integration
(progressive delaying of pixel outputs before summing)
proceeds much too fast to wash out small structure.

Cirrus clouds, on the other hand, will degrade
performance. The noise spectrum shown in Figure 4-6
results from barely perceivable clouds; and note that
the problem of cloud throughput and throughput fluc-
tuation has not been addressed at all. Typically,
cirrus cloud radiant structure overloads AMTA detector
amplifiers and precludes LWIR observation.

2) Sky Radiance Measurements

Utilization of atmospheric transmission models
e.g., LOWTRAN, to estimate the atmospheric transmission
along a path between a ground based infrared sensor
and an exo-atmospheric object can seriously limit
conclusions regarding the object's radiation character-
istics. The reason being that atmospheric models
incorporate model atmospheric profiles (temperature,
molecular constituent concentrations, etc.,) which
only approximate and, in some cases, deviate consider-
ably from the actual conditions prevailing at the time
of the measurement.

The primary objective of this experiment is to
develop a technique which will allow the atmospheric
transmission to be determined from sky radiance
measurements made with the AMTA sensor during the
measurement interval.

Experimental data and theoretical models
(Fig. 4-10, A) indicate that the spectral radiance,
N_a (λ), of the atmosphere can be expressed in terms
of an effective temperature, T_a, and an emissivity,
$\epsilon_\alpha(\lambda)$, i.e.,
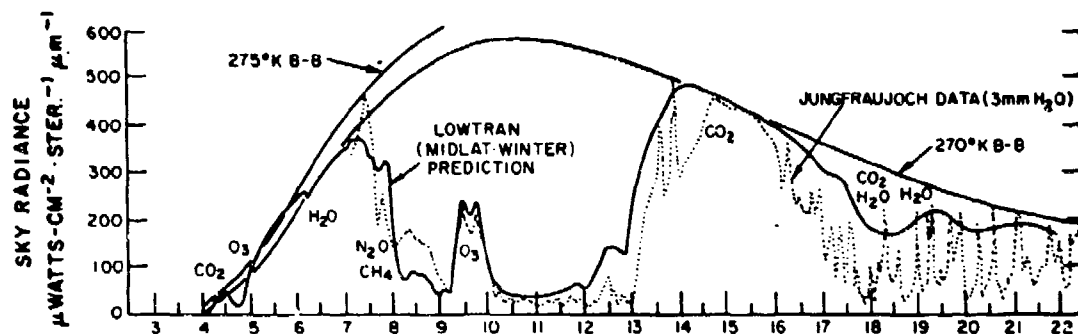
$$N_a \ (\lambda) = N_{oa}(T_a, \lambda) \epsilon_a(\lambda)$$

(A)
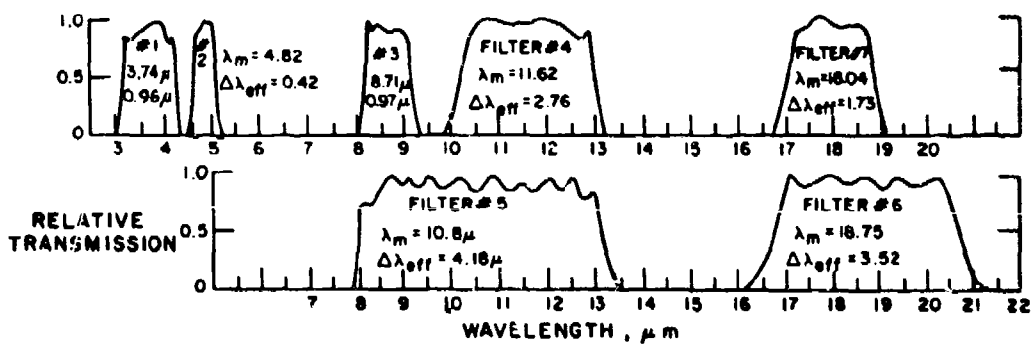
(B)

10-652

Figure 4-10.   Sky radiance/AMTA spectral bands.

where:

$N_{oa}(T_a, \lambda)$ is the spectral radiance of a blackbody
at the effective temperature of the atmosphere. Under
conditions of thermal equilibrium, conservation of
energy requires that:

$$\rho_a + \tau_a + \alpha_a = 1$$

where:

ρ_a = atmospheric reflectance (scattering)

τ_a = atmospheric transmission

α_a = atmospheric absorption

In the LWIR spectral region, the primary physical
process for attenuation of radiation passing through
the atmosphere is absorption and the effects of
scattering are negligible in comparison. Therefore,
under conditions of thermal equilibrium:

$$\tau_a + \alpha_a = 1$$

From Kirchoff's law, $\alpha_a = \epsilon_a$, therefore, it follows
that:

$$\tau_a = 1 - \epsilon_a$$

In principle then, a measurement of the radiance of
the atmosphere at an assumed effective temperature
will yield an emissivity from which the atmospheric
transmission can be derived.

The AMTA system is configured to allow measurement of atmospheric radiance in the several spectral bands shown in Figure 4-10, B.

The system transfer function which relates the detector dc voltage output to atmospheric radiance is;

$$N_{oa}(T_a)\epsilon_a = \left[\frac{V(EL) - V(F8)}{V(DC) - V(F8)} - \epsilon_o\right] \frac{N_b(T_{amb})}{1 - \epsilon_o}$$

and atmospheric transmission then becomes;

$$\tau_a = 1 - \left[\frac{V(EL) - V(F8)}{V(DC) - V(F8)} - \epsilon_o\right] \frac{N_b(T_{amb})}{(1 - \epsilon_o)N_{oa}(T_a)}$$

where:

$V(EL)$ = Detector dc output at elevation (EL);

$V(F8)$ = Detector dc output looking at Filter #8 ($\approx$ zero
background);

$V(DC)$ = Detector dc output looking at dust cover
($\approx$ ambient temperature blackbody);

$N_b(T_{amb})$ = In-band radiance of blackbody at
ambient temperature (T_{amb});

ϵ_o = Optical emissivity;

ϵ_a = Apparent atmospheric emissivity.

Therefore, atmospheric transmission can be derived from measured data and assumptions regarding the system

optical emisivity, ε_o, and the effective atmospheric
temperature, T_a. These assumed values obviously
place constraints on the precision to which the atmo-
spheric transmission can be determined.

Figures 4-11 and 4-12 show examples of reduced
data for filter 5 (10 μm) and filter 6 (20 μm)
for three different measurements. The LOWTRAN 3
mid-latitude summer transmission model is also plotted
on the figure to allow comparison of measured and
predicted transmission. Water vapor densities, given
on the figures, were derived from dew point measurements.
LOWTRAN water vapor density was taken from the AFCRL
publication, "Optical Properties of the Atmosphere"
(third edition). The curves show, as expected, that
the measured transmission can deviate considerably
from that predicted by the LOWTRAN 3 model. The
curves also show that atmospheric radiance and, hence,
transmission deviates considerably from day to day as
a consequence of the change in water vapor density.
Also, anomalous behavior at specific elevations is
readily seen. This preliminary analysis of the data
indicates that the technique can be used to determine
atmospheric transmission during a given measurement
interval.

ELEVATION ANGLE, DEGREES
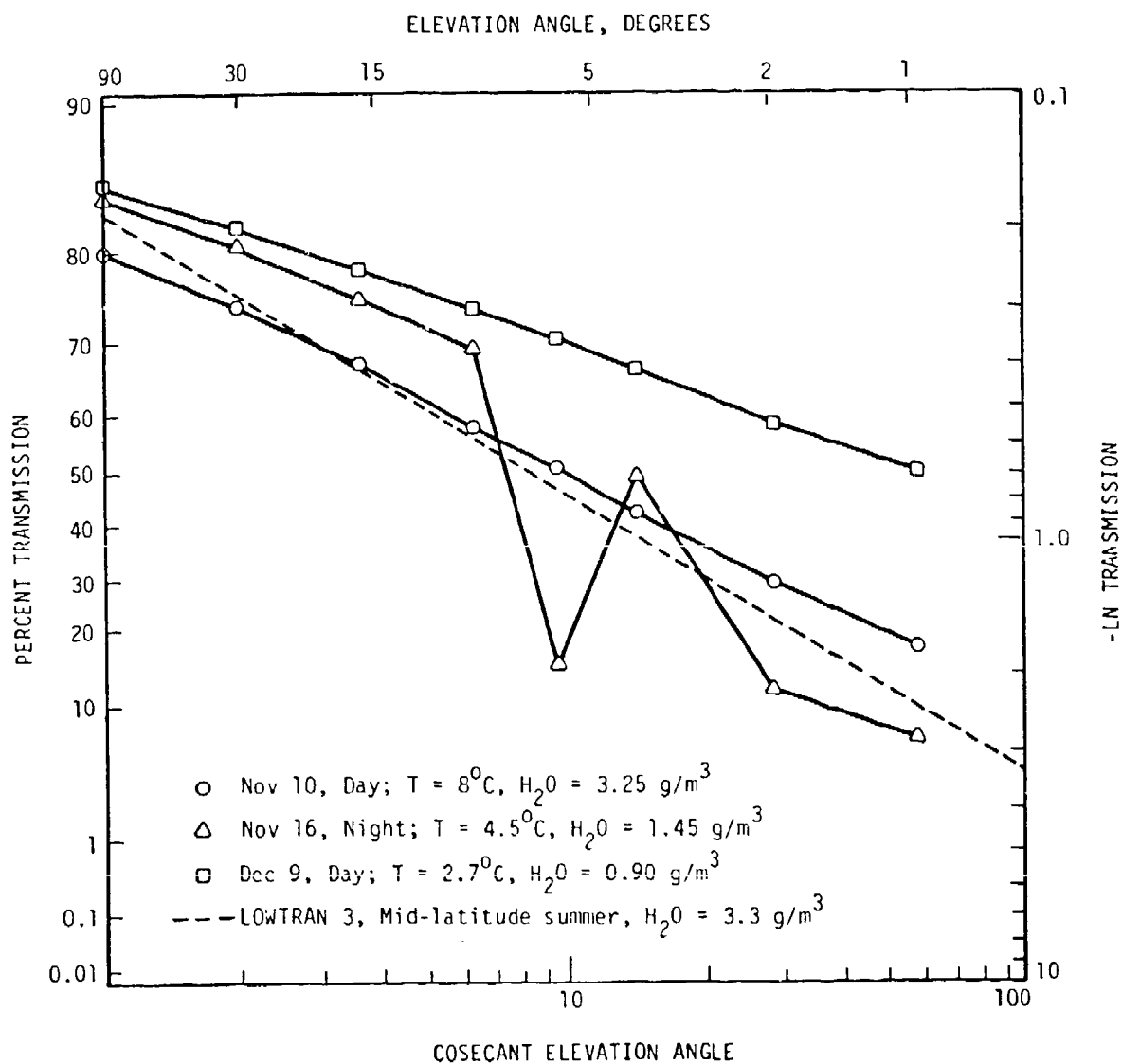
Figure 4-11.   Measured atmospheric transmission as a function of elevation, AMTA filter #5, 10 μ.

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ELEVATION ANGLE, DEGREES
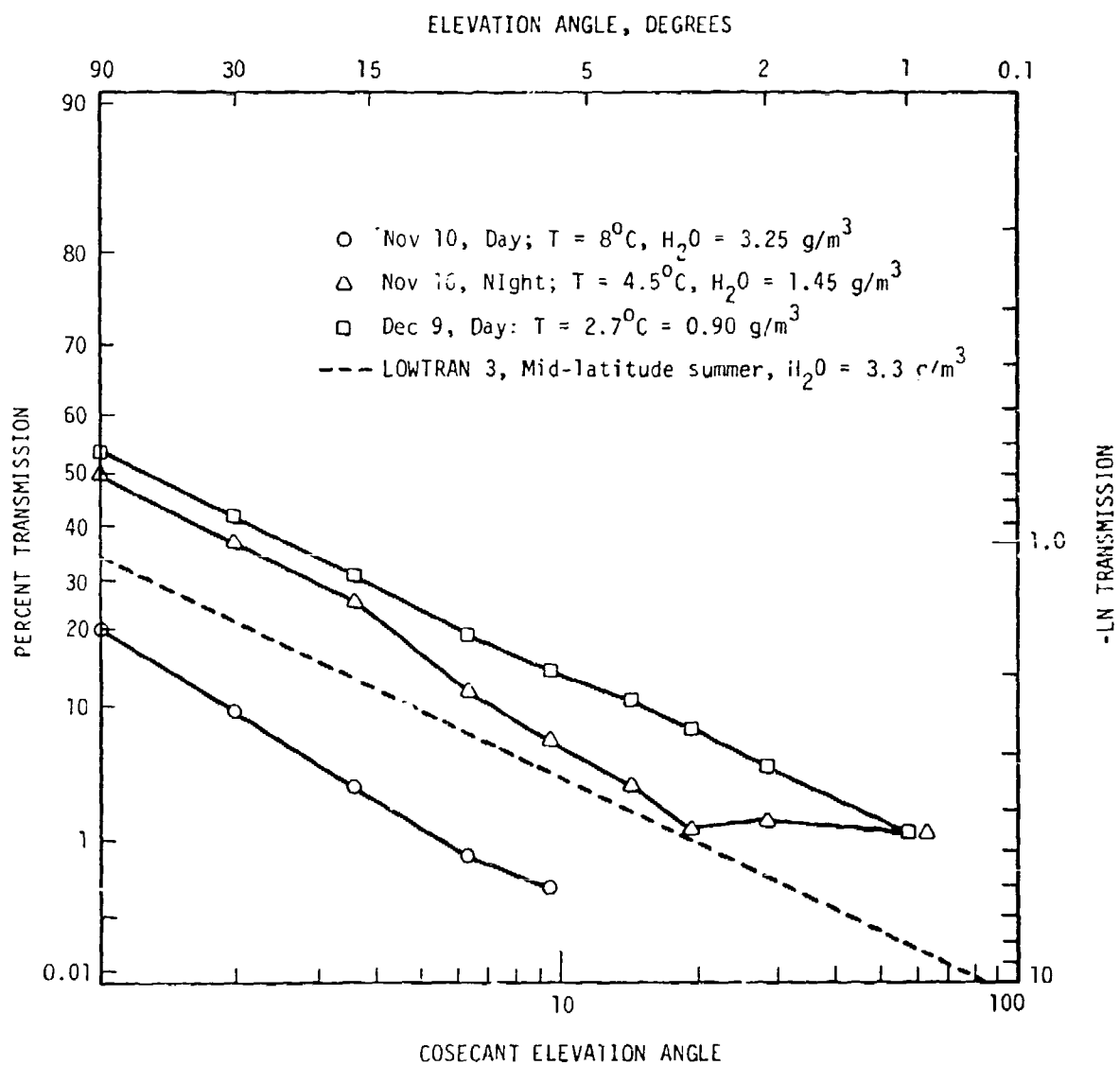
Figure 4-12.   Measured atmospheric transmission as a function of elevation, AMDA filter #6, 20 μr.

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3) Satellite Signature Measurements

As part of the AFWL program, the infrared measurement of satellites of interest has continued through the year. These signatures generally result in classified (.ta. Approximately 150 different satellites were identified for monitoring. These satellites were selected based on minimum expected irradiance levels and, therefore, are primarily low altitude targets with large areas.

Weekly AESOP computer runs are made on these 150 satellites which presents a listing of pass availability based on a given selection criteria. The usual criteria for visual acquisition specifies sunlit passes at either twilight or dawn that will cullminate at angles of 45 degrees or greater. Acceptable passes are placed on the AMOS weekly operating schedule. Data reduction of successful passes is generally performed on a single point basis (one radiant intensity value per pass at a selected time). Data collected from this program has been presented at the various interface and discussion meetings related to the overall program.

4.3.2 Visiting Experiments

The visiting experiment program was established to assist approved agencies and individuals in utilizing the unique capabilities of the AMOS Observatory.

A qualified systems interface engineer or scientist is assigned to each visiting experiment. In the early stages of experiment planning he makes contact with responsible personnel in charge of the proposed experiment and identifies and documents the user's requirements. The experimental definition and requirements result in the preparation of a MIOP which, after DARPA/RADC approval, becomes the governing document for the conduct of the program. Included in the MIOP is a brief description of the experiment and its objectives, a description of the sensors involved and their calibration, a scenario for the operation of the experiment, and the requirements for data collecting, data reduction and reports. The assigned scientist or engineer serves as the planning and communications focal point for the visiting experimenter, representing the official source of information who plans, schedules, and expedites the experimental program at AMOS.

He is also responsible for the design and fabrication of any interface hardware necessary to the conduct of the experiment. Where possible, existing facilities are configured to meet the program needs. It is also his responsibility to ensure that the experiment is performed safely and does not place the experimenter or any AMOS facilities in jeopardy.

During the initial year of the Phase IV contract, two experiments (Sandia Laser Experiment and Atmospheric Characterization Program) were performed, and a third (AFWL IR Measurements) was initiated. The following year of 1979 saw a repeat of the successful Sandia Laser Experiment using different satellites, a new program identified as both the SAMSO HF Laser Experiment and as Masking Effects Verification (MEV) program, and a continuation of the AFWL IR Measurements now identified as the ABTS Infrared Evaluation Experiment. In addition, discussions were held with various individuals and organizations which will likely lead to the Visiting Experiments and Measurements of 1980, 1981 and 1982.

4.3.2.1 Sandia Experiment II

A second series of laser illumination experiments using the AMOS and Sandia Ruby Lasers was conducted during the first half of July and generally followed the program as described in MIOP #30. Laser illumination response of two satellites to ruby light was evaluated. The first target identified as IIA is in synchronous orbit and required a full 24-hour calibration period. The second target, IIM, is in a 12-hour orbit which places it above the AMOS horizon only during the daylight hours. This second satellite was illuminated during a six-hour period centered about local noon. This second target presents particular difficulties since it could never (during the July test period) be observed visually. Accurate pointing had to be

accomplished in an absolute means by obtaining an accurate
mount model and relying on accurate state vectors describing
the instantaneous si ellite position in space.

The experiment successfully met both the objectives of
AMOS and Sandia. All necessary data was collected over a
nine-day period. Approximately 600 shots were fired with the
Sandia Laser. Half of these resulted in the successful
triggering of the Atmospheric Burst Locator (ABL) sensor on the
IIA target. The majority of the remaining 300 firings were used
during optical alignment of the laser system and to illuminate
the IIM target.

A major problem which was uncovered during the first test
series in 1978, pointing drift in the Laser Beam Director, was
solved. Extensive efforts were taken to shield the Beam Director
components from direct solar illumination and to provide the
optical expander with a continuous flow of cooled air.

A new problem was uncovered as the result of operating
during the daytime hours. Initiating a satellite track after
00:00 UT time (2 p.m. local) with a state vector epoch for an
earlier time period resulted in a pointing vector which was in
error by one day. The problem could be circumvented by
maintaining a continuous track on the target which had been
established prior to the day change; however, this procedure
precluded the use of stellar pointing checks or alternate use
of the computer during predictive avoidance intervals. It had

never been a requirement in the past for the computer software programs to keep track of the absolute day change.

4.3.2.2 Masking Effects Verification

Through a series of meetings, which were initiated in late 1978 and continued through the spring of 1979, a visiting experiment first known as the SAMSO HF Laser Experiment and later as Masking Effects Verification (MEV) was established. The experiment involved the illumination and calibration of three satellites with a hydrogen fluoride laser operating in the IR spectrum. The experiment was performed with assistance of scientists and engineers from the Aerospace Corporation and Aerojet ElectroSystems under sponsorship of SAMSO.

The experimental package (fabricated by Aerojet) includes a 20 watt HF CW laser, a modulator, calibrated attenuators, transfer optics, alignment lasers and an AMOS supplied boresight ISIT-TV. The package was attached to the rear Blanchard of the 1.6 m Telescope which provided the narrow beam widths required by the experiment. Portions of the experiment required pointing precision which exceeded the normal one arcsecond resolution provided by the AMOS software. Special provisions were made to enable the console operator to execute 0.5 arcsecond steps during the experimental period by developing a modified version of the mount control software.

The HF laser and associated optical package required a considerable amount of support hardware and equipment. Included were numerous bottles of helium, hydrogen, oxygen and sulfur hexafluoride for laser operations, a high voltage power supply and ballast control, a large vaccuum system, two water cooling heat exchangers and a rather complex scrubber system used to clean the exhaust gas effuents of harmful products. Many of the support items were supplied in duplicate to insure a successful program with minimum downtime. The total mass of equipment brought to the Observatory exceeded 80,000 pounds. Approximately 37,000 pounds were flown in to Kahului on a C-141 jet aircraft and the remainder was surfaced shipped from the mainland and Honolulu.

The magnitude of the equipment can best be visualized, with the three photos, Figures 4-13, 4-14, and 4-15. Figure 4-13 shows the optical package (with its protective cover removed) as it was mounted to the rear Blanchard surface of the 1.6 m Telescope. The glow discharge from three tubes which form part of the cavity of the HF laser can be seen as well as portions of the HeNe laser alignment system. Gas, power and vacuum lines reach the package via a cable drape system which is attached to the telescope. This photo was taken with the 1.6 m Telescope placed in a horizontal position where the 1.6 m optical flat was used in auto-collimation for precise alignment of the laser to the optical axis of the telescope.
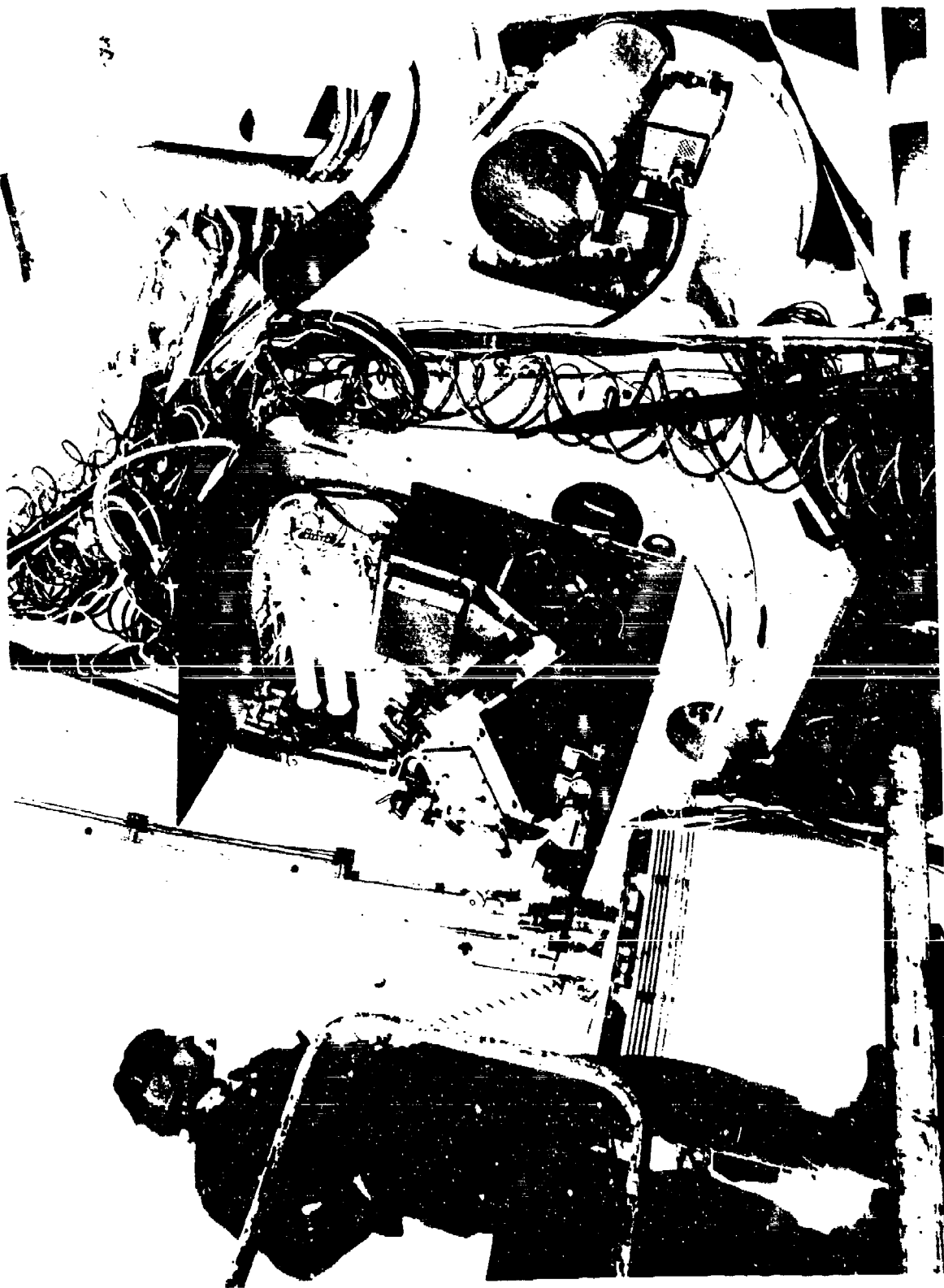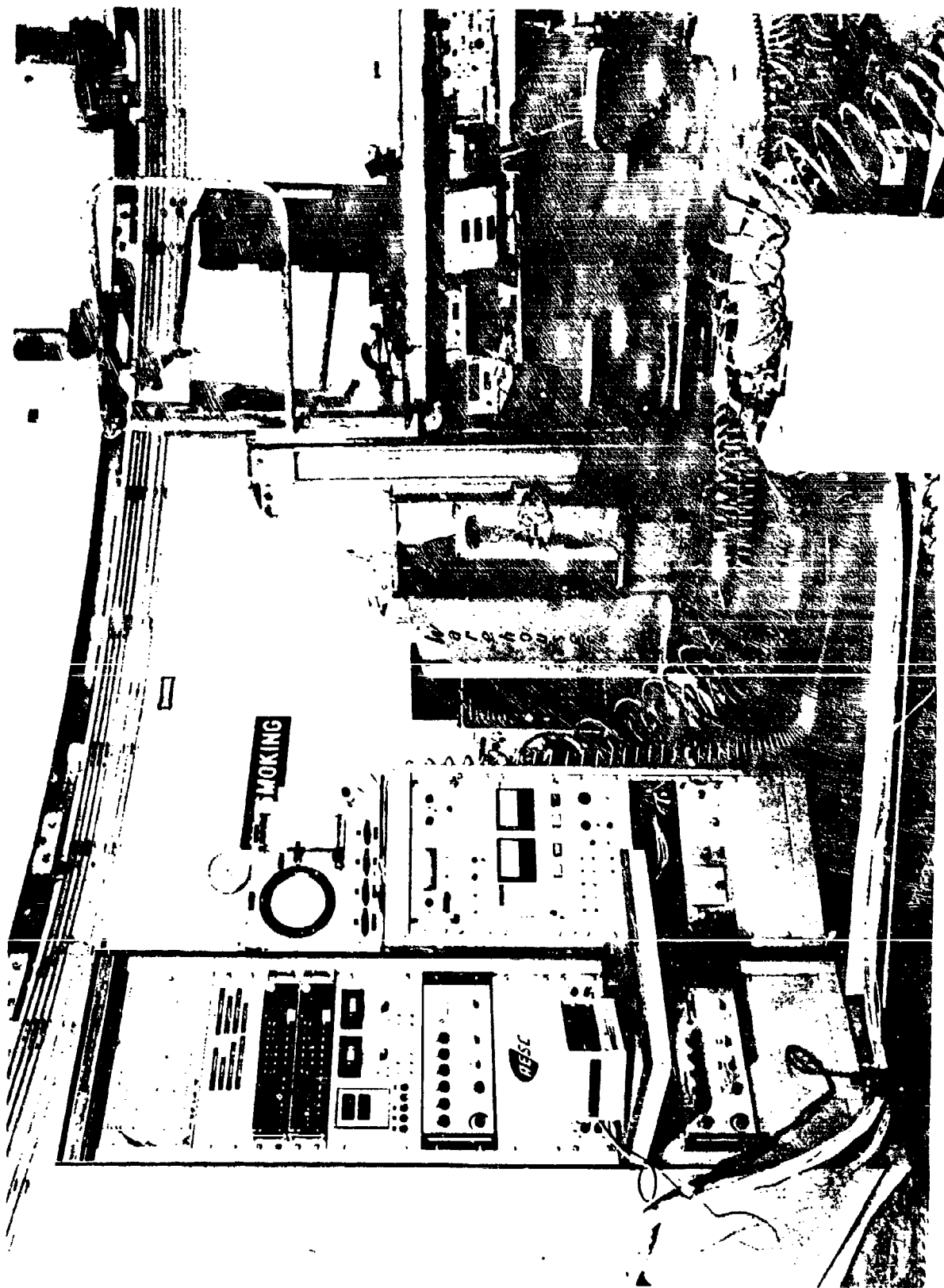
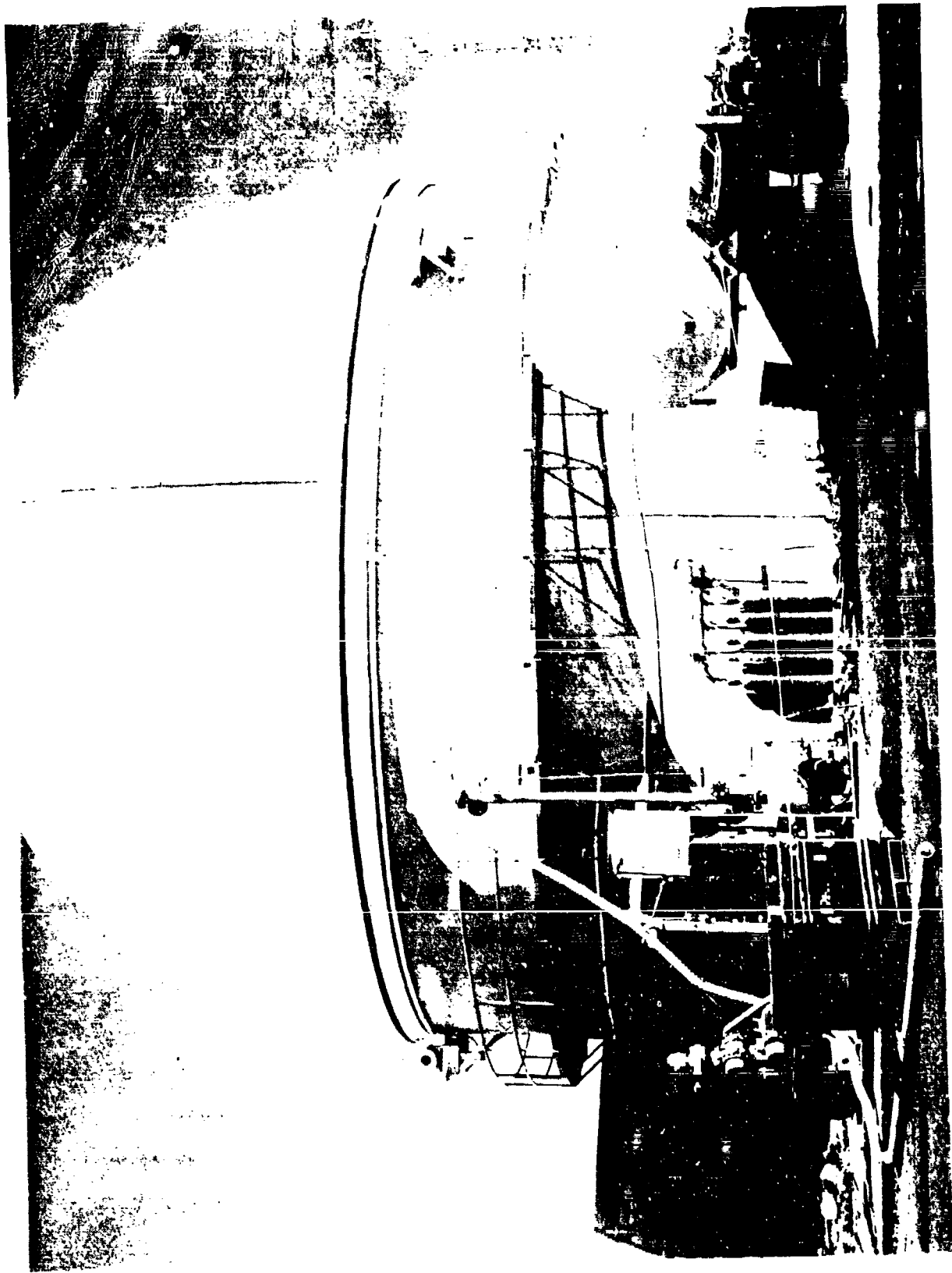Figure 4-13. MEV optical package.

Figure 4-14. MEV control equipment.

Figure 4-15. MEV equipment located exterior to observatory.

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Figure 4-14 shows some of the control equipment needed for the optical modulator and attenuators as well as the gas flow regulators. Not shown, but located on the lower level of the dome, were the high voltage power supplies and laser ballast resistors. Special heat flow tubes were constructed to transfer 30 kilowatts of heat from the ballast to the inside of the Observatory to keep heat from the dome and to conserve energy.

A portion of the equipment located exterior to the Observatory is shown in Figure 4-15. A storage tank containing 3,000 gallons of liquid nitrogen was used to provide gaseous nitrogen to purge the system before and after each day's activity. Two tanks were required during the course of the two month experimental period. Special racks were constructed to hold thirteen gas bottles along the exterior of the dome walls. A portion of the vacuum pump and the exhaust scrubber system can be seen near the entrance door to the lower dome. Not shown are the two heat exchangers which were located nearer to the front entrance to the observatory and the gas exhaust tower which was located 100 feet across the road and down wind from the Observatory.

The experiment started on 27 July 1979 with the arrival of the C-141 aircraft and nine pallets of equipment which were off-loaded and transferred to the Observatory the same day aboard two 40 foot flatbed trucks. The following Monday, 30 July,

27 pallets of gas bottles arrived by Matson freight and were taken to the Observatory. The next three weeks were devoted to equipment set-up, checkout and alignment. A period of poor weather delayed actual satellite operations until 23 August. Following another brief period of corrective action to improve laser performance (the laser was found to be attitude sensitive requiring frequent realignment) and operational procedures, satellite illumination continued through the month of September. All equipment was disassembled during the first week of October and surface shipped back to Aerojet.

During the two-month measurement period, three different satellites were illuminated. A large variety of measurements were performed utilizing variations in laser modulation waveforms and power levels. Data resulting from this program will be analyzed and reduced by Aerojet ElectroSystems and Aerospace. AMOS will provide inputs in the form of satellite tracking and trajectory data from 26 computer generated history tapes, and strip chart records of atmospheric seeing conditions recorded during the illumination periods.

4.3.2.3   AFWL IR FLIR Measurement

As part of the AFWL IR Measurement program discussed in Section 4.3.1.2, a visiting experiment will be conducted at AMOS during the months of March, April and May of 1980. This

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experiment was orginally scheduled for 1979. However, hardware difficulties with certain portions of the package and the need for a thorough evaluation of the total system forced postponement.

The experiment will evaluate the performance of an infrared adaptive optical system designed to correct for the effects of atmospherically induced optical turbulence while tracking low altitude, extended area, satellites. The equipment consists of an optical package designated as the AMOS Breadboard Test System (ABTS) which will be mounted to the rear Blanchard surface of the 1.6 m Telescope and the system control and processing electronics which will be housed within Room 26 of the Observatory.

The telescope mounted components which comprise the ABTS package are shown schematically in Figure 4-16. The components include:

1) a FFIM (Far-Field Irradiance Maximizer), essentially an infrared shearing interferometer, which detects wavefront errors caused by atmospheric effects;

2) a Tip/Tilt or Steering Mirror which corrects wavefront tilts;

3) a Piezoelectric Deformable Mirror which compensates for atmospherically induced higher order aberrations; and

4) a FLIR (Forward Looking Infrared) sensor which provides a corrected TV image of the target.

The package requires a four-inch diameter collimated input. To satisfy this requirement, a negative lens is being installed
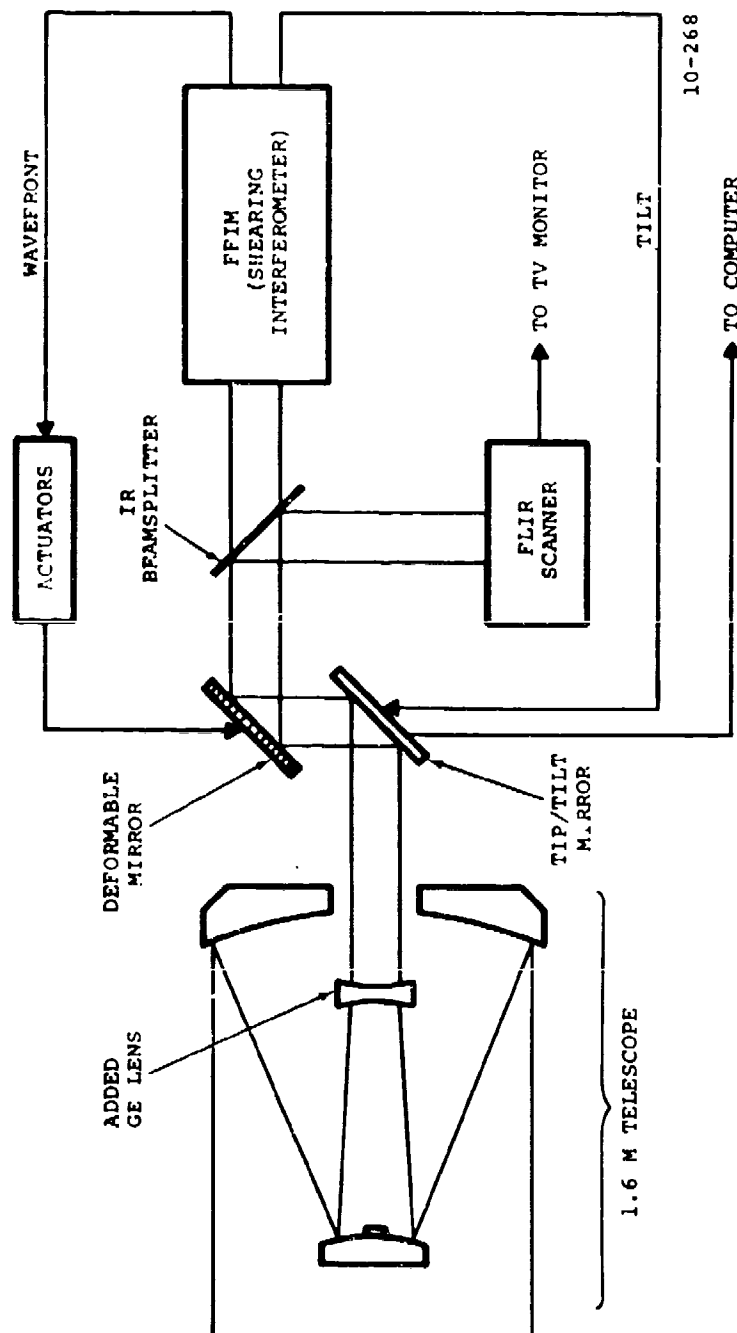
- 98 -

Figure 4-16. ABTS package schematic.

10-268

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within the f/16 converging beam. The lens is being mounted on the tertiary mirror drive system which presently exists within the 1.6 m Telescope. It will be positioned such that, when the tertiary mirror is rotated into position, the lens is rotated out of the beam and vice versa. The side Blanchard surface of the telescope can then be used in a normal manner for other experiments.

The ABTS control and processing electronics will be assembled in Room 26 of the Observatory. Included will be signal processing and control computers, high voltage drivers for the deformable mirror, video control and display for the FLIR and other ancillary equipment.

AMTA Track/Search System

The AMTA sensor will be used during a portion of the measurement program for initial target acquisition. Modifications are being made to AMTA to provide an automatic search and track capability. As part of this system up-grade, a linear scan mechanism was added to the B29 secondary mirror of the 1.2 m Telescopes. This mirror performs the toggling function necessary for AMTA background rejection and forms a portion of the search pattern.

The linear scan mechanism was completed and installed in the summer of 1979. A modification of the scan rate, from 45 Hertz normally used by AMTA to 50 Hertz, enabled the system to be compatible with the Contrast Mode Photometer (CMP) which

shares the same telescope beam with AMTA. The system is operational and is being used on a routine basis for the gathering of both IR and photometric signature data.

A simplified block diagram of the drive electronics is shown in Figure 4-17. The basic components are a 600-Watt servo amplifier, mirror position and velocity feedback, and the scan mechanism itself which is driven by a pair of linear motors. A sketch of the scan mechanism is shown in Figure 4-18. The mirror is rotated about its center of mass on a frictionless flex bearing. The actual movement of the edge of the mirror, required to achieve the 20 to 60 arcsecond scan amplitude, is on the order of a few thousandths of an inch. The Infomag linear motors (originally designed for use in computer disc drives) were modified to provide increased force at the expense of reduced drive length (originally one inch) by a redesign of the moveable coil. A LVDT position and a moving magnet velocity transducer were added to form a stable, responsive, type II servo loop. The mechanism includes provisions for independent centering and tilt adjustment of the secondary mirror as necessary for telescope alignment.

The scan amplitude and frequency of the mirror are remotely and independently adjustable. At present, three different scan amplitudes are envisioned. The normal toggle amplitude of 23 arcseconds is presently being used for routine measurements. A microprocessor controlled system is under development which
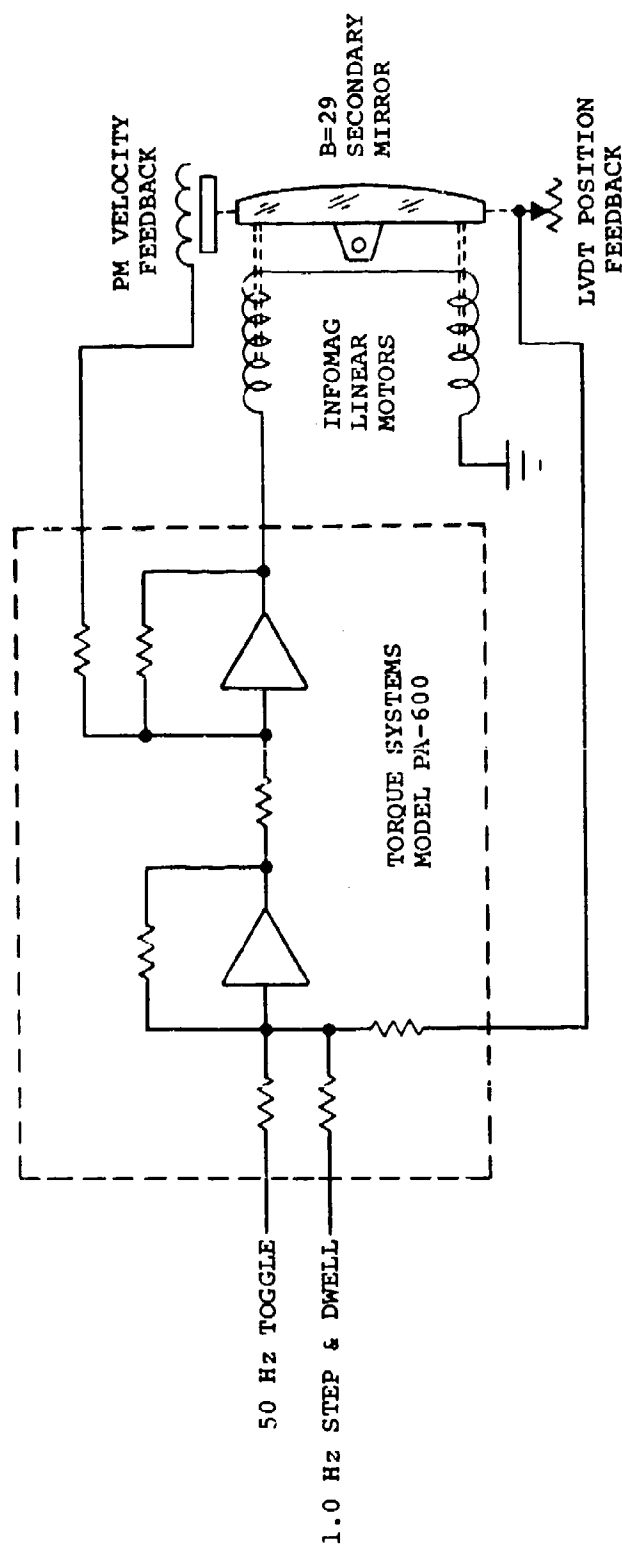
Figure 4-17. Secondary mirror linear scan drive system.

SECONDARY MIRROR
1.2m, b=29
(DIAMETER 8.25 IN)

VELOCITY
TRANSDUCER

VOICE COIL
DRIVER MOTOR 2

10-322A

FLEX BEARING

POSITION
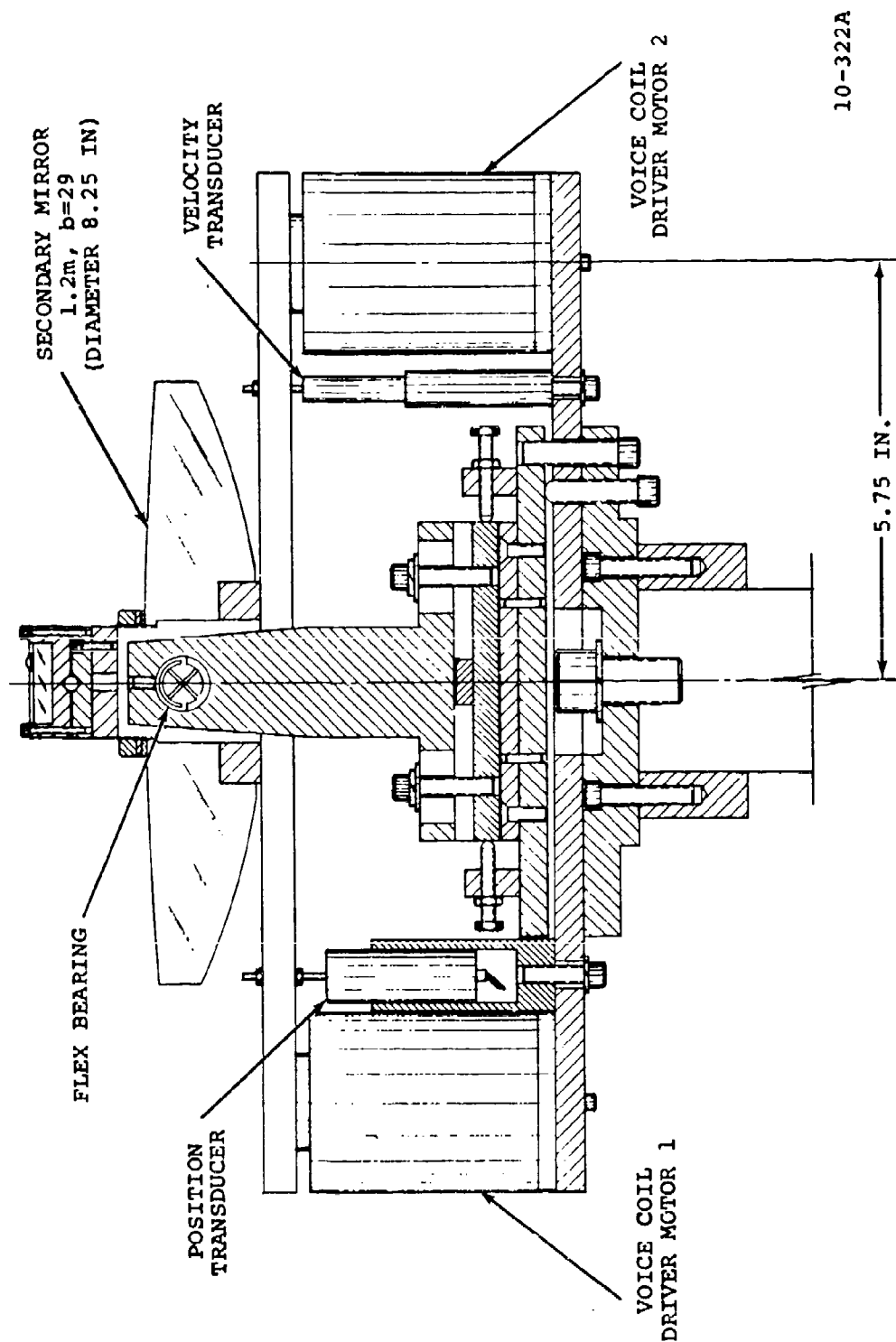TRANSDUCER

VOICE COIL
DRIVER MOTOR 1

5.75 IN.

Figure 4-18.   Secondary mirror scan mechanism.

will provide AMTA with automated functions of both target search
and track modes in which scan amplitudes of 56 arcseconds will
be used for search and 32 arcseconds will be used for tracking.

The search pattern was developed to cover the approximately
7 by 16 arcminute field-of-view found necessary under the
acquisition off-set study performed as part of the Satellite
Signature Measurements. A sketch of this search pattern, which
uses a combination of declination and polar axis scanning is
shown in Figure 4-19. The 80 by 80 arcsecond AMTA field-of-
view is toggled between two states separated by 56 arcseconds
for a period of approximately one second. At the end of each
second, the scan area is moved 112 arcseconds in declination
and 14 arcseconds in polar angle until the total field is
covered in approximately 68 seconds. This particular pattern
has not been finalized yet and another pattern is also under
consideration. However, it is certain that the declination scan
will be accomplished by movement of the scanning secondary
mirror and the polar axis movement will accomplished by movement
of the entire telescope.

Once the target is located with the search pattern, a track
mode is initiated by reducing the toggle scan amplitude to 32
arcseconds and by placing the target at the intersection of
four detectors of the AMTA array to form X-Y or polar/declination
error signals by subtraction of opposing detector outputs.

AMTA SEARCH PATTERN
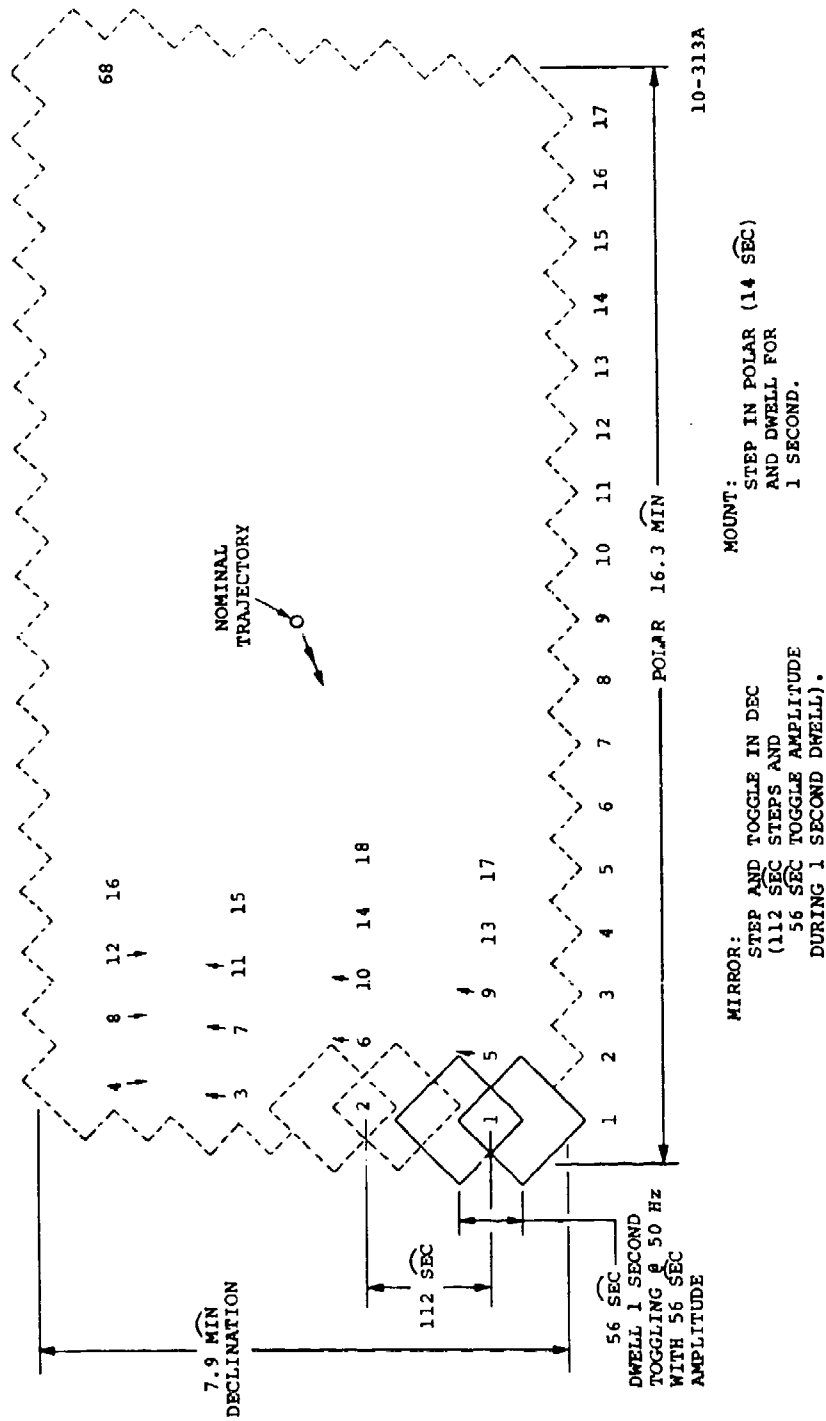(RASTER SCAN, 50% EFFICIENT)

Figure 4-19. AMTA search pattern.

While four of the detectors serve to guide the tracking of the target, a central detector is used to gather target signature data. The target is caused to alternate between the two states at a 50 Hertz rate.

The entire system will be under microprocessor control. The software algorithms provide convenience of operation and versatility for changes or additions. The main microprocessor objectives are to:

1) generate a search pattern around the nominal trajectory;

2) detect a target by processing data from the 25 AMTA infrared detectors; and

3) generate error signals which center the telescope on the target and maintain track.

During the summer of 1979, the basic system approach to accomplish these objectives was refined and definitized from earlier concepts. The real-time operating system for the microprocessor was structured, and software coding initiated.

Software routines related to the search mode have been written and coding of the detection routines is in process. Interrupt routines which provide initialization and testing of the overall system have also been written. Software which generates the AMTA mirror toggle signal and search pattern stepping signals has also been written and was demonstrated in the latter part of 1979.

The hardware of the system has been assembled using micro-processor compatible subsystem boards, and additional special circuitry has been prototyped. Currently, phase-locked loop circuitry and a timing signal interface is being fabricated to provide hardware a timing synchronization of the microprocessor system to the Observatory. The completed system will be ready in March 1980.

4.3.3   Large System Tests

In contrast to the type of program support discussed in Sections 4.3.1 and 4.3.2 which involves use of existing or slightly modified AMOS instrumentation (Measurement Programs) or temporary installation of special hardware (Visiting Experiments), certain major development activities are included in the Phase IV program. These activities are identified as Large System Tests and, in particular, include the DARPA Compensated Imaging System (CIS) program, the classical imaging data base and the atmospherics data base.

4.3.3.1   Compensated Imaging System (CIS) Interface

Support for the DARPA CIS program constitutes a major effort in the AMOS Phase IV program.

As is the case for visiting experiments and certain measure-ment programs, AMOS has designated a CIS Interface Scientist for the Compensated Imaging System activity. He is responsible for interaction with RADC, Itek, and AERL Everett personnel and, in

general, for assuring that the CIS is installed efficiently and on schedule at AMOS.

AMOS/CIS interface activities began early in Phase III and included participation in CIS design reviews, preparation of Interface Information Documents (IID's) and definition/implementation of special tests.

Interface activities and special testing related to the CIS have continued during Phase IV and are expected to increase in scope and intensity as the delivery date for CIS hardware draws near.

When the hardware arrives on-site, AERL will install the equipment on the 1.6 m Telescope and in the CIS control room and interface the system to the AMOS computer, timing and control systems. During the CIS evaluation period, AMOS will provide mission planning, operations, and technical support.

Significant Phase IV CIS activities during 1979 included the completion of major modifications to the AMOS facility for the CIS hardware, and the design and implementation of special tests on the 1.6 m Telescope to assure compatibility with the Itek equipment.

Facility Modifications

In order to meet the requirements of both the DARPA Compensated Imaging System and the MOTIF program, certain modifications and improvements were made to the AMOS facility. Based upon a preliminary study (AMOS/MOTIF Space Allocation and

System Interface Requirements Study, AERL, January, 1977) and a
subsequent quote from a local construction firm, funding was
included in the Phase IV contract to cover anticipated costs.

The Phase IV Program Plan scheduled the work to be accom-
plished during the period May-December 1978. This effort
included a revision of the preliminary study, obtainment of
necessary subcontractors' bids, awarding of subcontracts and
implementation of the modifications along with certain tasks to
be accomplished by AMOS personnel. The initial goal was to
accomplish both the MOTIF and CIS tasks in parallel and complete
the effort by 31 December 1978.

After the Phase IV contract was initiated on 1 January 1978,
several facts became apparent.

1) Many specific requirements for CIS-related modifica-
   tions were not firm. An AMOS/CIS Interface Meeting
   held in April of 1978 produced twenty-seven (27)
   action items for resolution, many of which involved
   the implementation of facility modifications. AMOS
   staff members worked with RADC, Itek and AERL Everett
   personnel during the spring and summer of 1978 to
   complete the action items and come to agreement on
   specifics.

2) Since the CIS hardware was not scheduled to arrive on
   Maui until 1980, no real need existed to have the AMOS
   facility ready for CIS until that time. (Decisions

that impact Itek and/or AERL Everett designs would, of course, be addressed separately.)

3) MOTIF schedules required certain modifications to be completed by early 1979 in order to install and test the new DTS and CMS hardware.

Based upon the above, the task was reprogrammed in July 1978.

1) MOTIF and CIS tasks were to be treated separately wherever possible.

2) MOTIF tasks were to be completed by 1 January 1979 if possible.

3) After necessary CIS modifications had been completely defined, a revised plan/specification was issued which was suitable for obtaining firm contractor's bids. The revised plan also contained a schedule to assure that the work was completed in a timely manner with respect to CIS requirements.

During July, interface meetings were held at Everett, Itek and RADC to discuss specific items of the Facility Modifications task in addition to the general approach described above. A reappraisal of MOTIF requirements was conducted. It was determined that the equipment could be installed in the existing computer and communications area with minimum interior construction. Included in this approach was removal of the wall between room 41 and 42 and the addition of a door between rooms 41 and 47.

The purpose of the changes was to accommodate the relocation of personnel and facilitate the addition of the MOTIF MODCOMP V computer. Electrical distribution changes in this area were also included. Several questions pertaining to CIS requirements were still pending; specifically, air conditioning requirements for room 22, door sizes, dome chiller location and CIS equipment handling requirements. A raised floor was added to room 25 and the air handling unit for the air conditioner was moved to that location. The raised floor acts as the air supply with room 26 serving as the return plenum. During the month of August 1978, it was determined that all MOTIF-related tasks could be completed by the first week in January 1979. Modifications to room 26 for CIS could also be completed in 1979 to support the Air Force IR measurement program which requires basically the same facilities as CIS. Remaining modifications would be completed as specific requirements were determined.

In September 1978 an engineering firm was engaged to prepare specifications for the MOTIF and CIS electrical modifications. Drawings and specifications for the CIS air conditioning system were sent to a Carrier Corporation engineer in Honolulu for review. At this time it was determined that Carrier could not supply a unit in a timely manner. A substitute air conditioner was selected from Liebert Corporation in Columbus, Ohio and arrived on-site in December 1978. This unit had nearly identical capabilities and physical characteristics as the originally

selected Carrier unit. At this time, a revised schedule was prepared to satisfy specific priorities.

During the month of October 1978, all facility modification design work was completed. The AMOS/MOTIF Space Allocation and Interface Definition document was revised and submitted to RADC for approval. A bid package was prepared. When approval from RADC was received in November, competitive bids were sought. Proposal packages were sent to seven local contractors and an advertisement was placed in the Maui News. A bidders' conference was held on 22 November 1978. The deadline for receipt of bids was 8 December 1978 with work scheduled to commence in January 1979.

Bids were received from two contracting firms. A review of the bid sheets revealed an obvious misunderstanding of what materials were to be purchased by AERL. Both bids were higher than allocated subcontract funds. A meeting was held with both contractors and available subcontractors to clarify material requirements and to ask for a rebid on the original specifications. In addition, revised specifications were prepared eliminating particular items and relocating the CIS chiller and the room 26 air conditioning condensing unit to the north side of the Observatory. This relocation eliminates the trenching, steel and concrete work for the trench, and the enlargement of the existing air conditioning equipment enclosure.

Installation of these thermal sources on the north side of the building is undesirable from a technical standpoint because

of the direction of the prevailing winds at AMOS. The ideal location is on the south side. Unfortunately, tentative plans for location of GEODSS facilities precluded use of this area.

New bids were prepared by the contractors and submitted to AERL on 28 December 1978. The low bidder on both proposals was Fuku Contruction, Inc.

Of the twenty subtasks that comprised the original bid, Fuku Contruction was awarded a subcontract to complete eleven, AERL performed five, and four were deleted.

The decision to perform some of the subtasks using AERL labor was made after evaluating the bids submitted by both Service Contracting and Fuku Construction. The subcontract costs were compared with the cost of performing the work in a timely manner using AERL technicians.

A decision was made to delete the installation of an additional door in room 5, leading to the main hallway (room 16). Three other subtasks (trenching, concrete and steel work for the trench, and an extended air conditioning enclosure) were deleted. They are not required with the installation of the room 26 air conditioner and Itek chiller on the north side of the Observatory.

Fuku Construction was placed under contract and work began in February 1979. The contract stipulated two completion dates; 1 March 1979 for the completion of electrical work in rooms 39, 40, 41, and 42, and 15 June 1979 for the remainder of the work.

All subcontract work was to be completed by 30 April 1979 with the exception of the raised floor in room 26. Delivery of this item had been extended by the supplier.

Except for a few items to be completed by the air conditioning subcontractor, all tasks were actually completed by the end of September 1979. The work was performed within the allocated budget. Modifications required for the new MOTIF systems were completed on schedule. The remaining open items will be completed in time to support the CIS system. Many of the modifications will also be used to support the ABTS Infrared Evaluation Experiment in March of 1980.

The interior of the main Observatory building was painted with the exception of the interior of the 1.6 m Dome. This area could not be painted before the cold weather set in due to the presence of the SAMSO MEV experiment.

Although not part of the original scope of work, portions of the observatory exterior were scraped, sealed and repainted.

The following mechanical tasks have been completed:

1) Provide reinforced concrete pads for Itek chiller and room 26 air conditioner on the north side of the main Observatory building;

2) Install plenum (raised) floor in rooms 25 and 26;

3) Install dropped ceiling in room 26;

4) Lower ceiling in room 16 (main building);

5) Provide chiller lines per Itek requirements from the outside chiller to high voltage power supplies, rear Blanchard assembly, and room 22;

6) Remove wall between rooms 41 and 42 to provide a single room for the data transmission system and spare computer;

7) Install a door between rooms 7 and 41 to allow computer operator access from office to equipment area;

8) Modify room 26 entrance door to account for the new plenum floor;

9) Modify doors between rooms 25 and 26, and between 25 and 22, to allow passage of air to the air conditioner in room 25;

10) Modify wall and door between rooms 24 and 25 to provide maintenance access to the air conditioner in room 25;

11) Install a ten-ton air conditioner for rooms 22 and 26 in room 25;

12) Install a new stove, refrigerator and microwave oven in the kitchen;

13) Enlarge the cage in the technical support building used to store spare parts; and

14) Paint the interior of the main Observatory building.
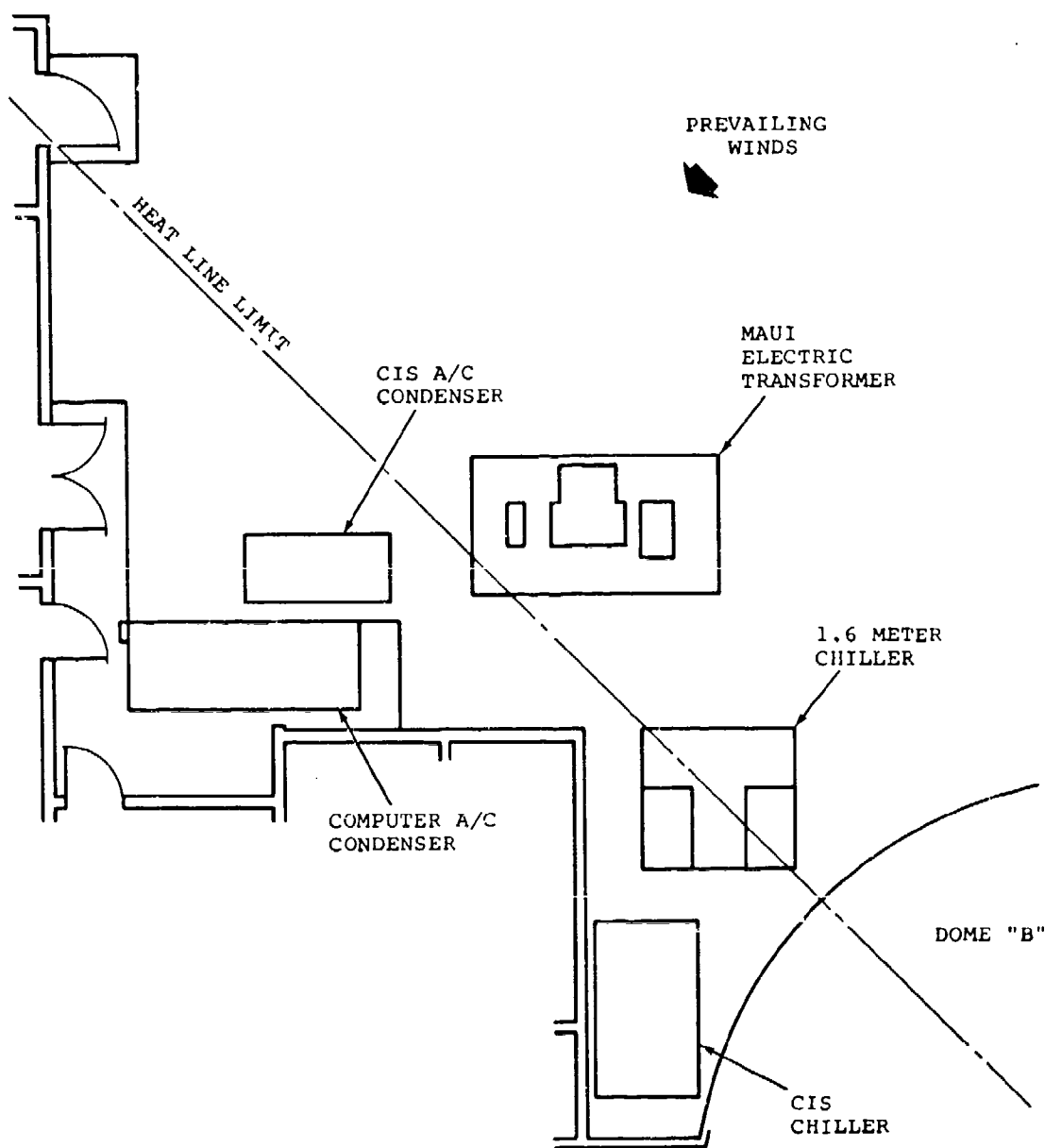
The following electrical tasks were completed:

1) Supply electrical power to the CIS and Data Recording System (DRS) equipment in room 26 and the air conditioner in room 25;

2) Provide electrical power to CIS telescope mounted equipment and the Monolithic Piezoelectric Mirror (MPM) power supply;

3) Provide electrical power to the CIS test room (room 22), for the CIS rear Blanchard assembly;

4) Provide power to the CIS chiller and the room 26 condenser on the north side of the Observatory;

5) Install safety disconnects for the entire CIS, including air conditioning, rooms 22, 24, 26 and 30. Install safety disconnects in rooms 22, 26 and 30 for the dome high voltage supply;

6) Provide power for the MOTIF Communications System (CS) in room 39 and the Data Transmission System (DTS) in room 42;

7) Install fluorescent lamps in room 26 to provide 100 foot-candles of illumination. Also, provide dimmable incandescent lighting in rooms 26 and 42. Install emergency lighting in rooms 22 and 26.

Figures 4-20 through 4-23 show the location of the MOTIF and CIS items as a result of the completed Facility Modifications tasks.

1.6 m Telescope Inertia Tests

Several tests were conducted in 1978 to assure that the mass of the CIS equipment would not significantly degrade the performance of the 1.6 m Telescope. Particular attention was

PREVAILING
WINDS

HEAT LINE LIMIT

CIS A/C
CONDENSER

MAUI
ELECTRIC
TRANSFORMER

1.6 METER
CHILLER

COMPUTER A/C
CONDENSER

DOME "B"

CIS
CHILLER

10-12

Figure 4-20.   CIS chiller and air conditioner location.
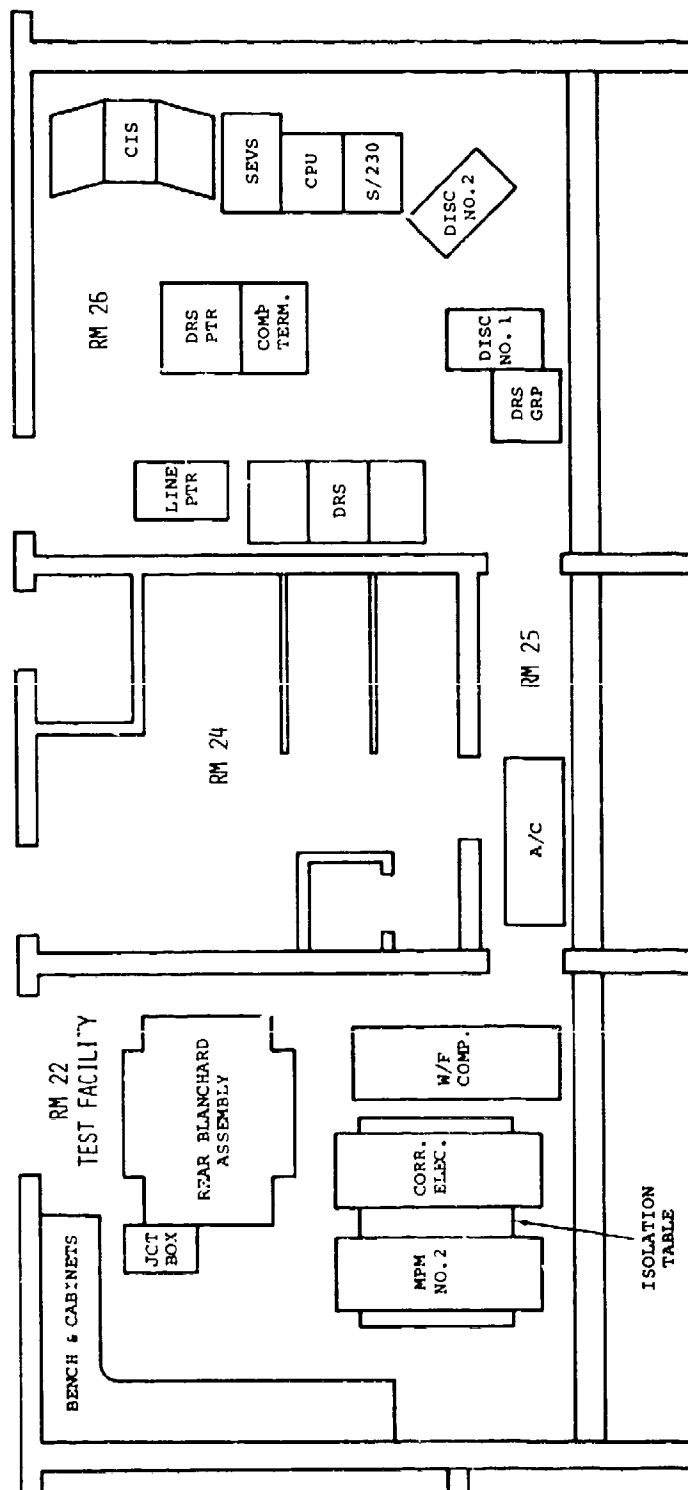
Figure 4-21. CIS equipment location.

10-346

RM 26

CIS

SEVS

CPU

S/230

DISC NO. 2

DRS PTR

COMP TERM.

DISC NO. 1

DRS GRP

LINE PTR

DRS

RM 24

RM 25

A/C

RM 22
TEST FACILITY

REAR BLANCHARD ASSEMBLY

JCT BOX

BENCH & CABINETS

W/F COMP.

CORR. ELEC.

MPM NO.2

ISOLATION TABLE
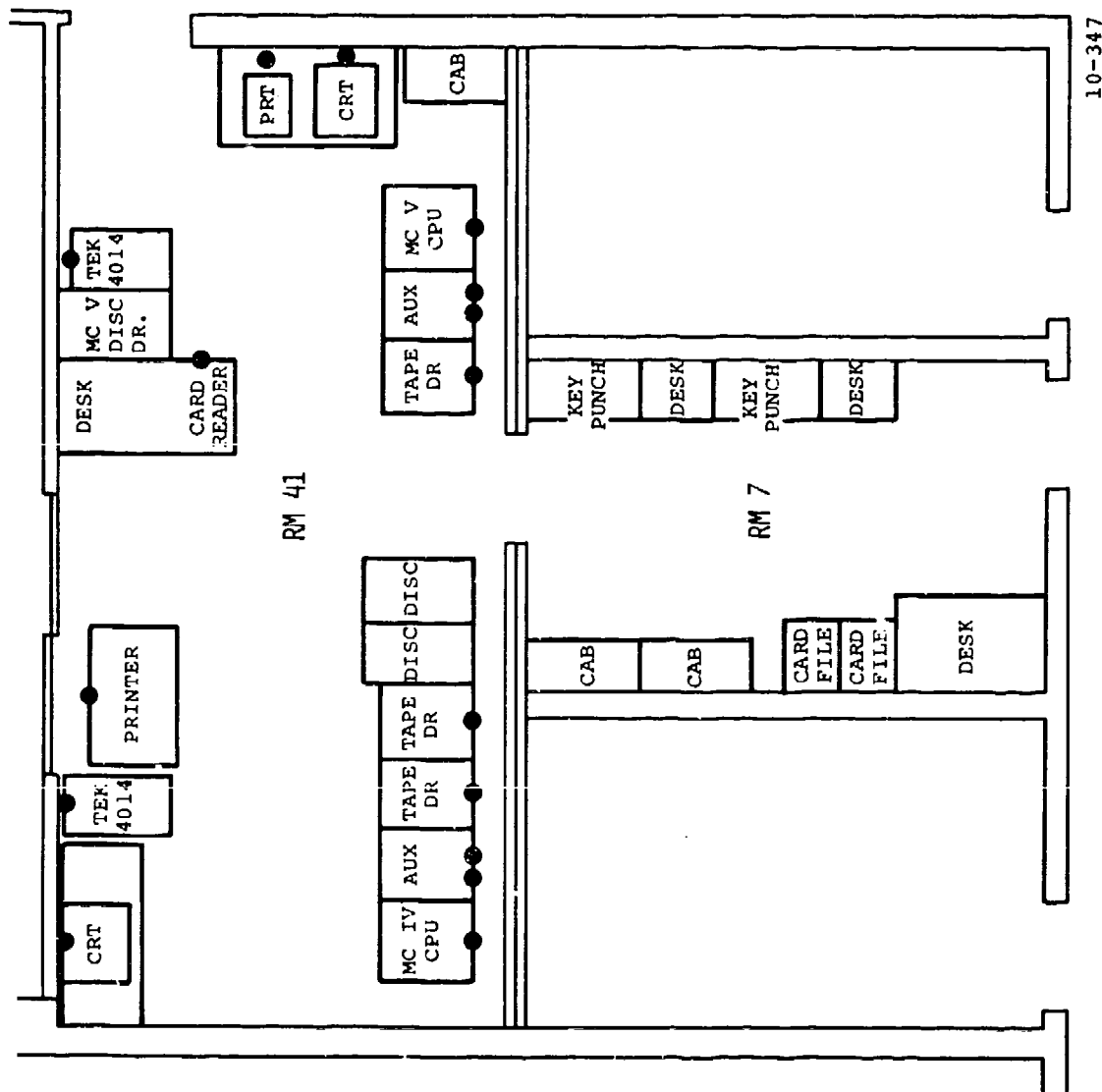
Figure 4-22. MOTIF equipment location, rooms 7 and 41.

10-347
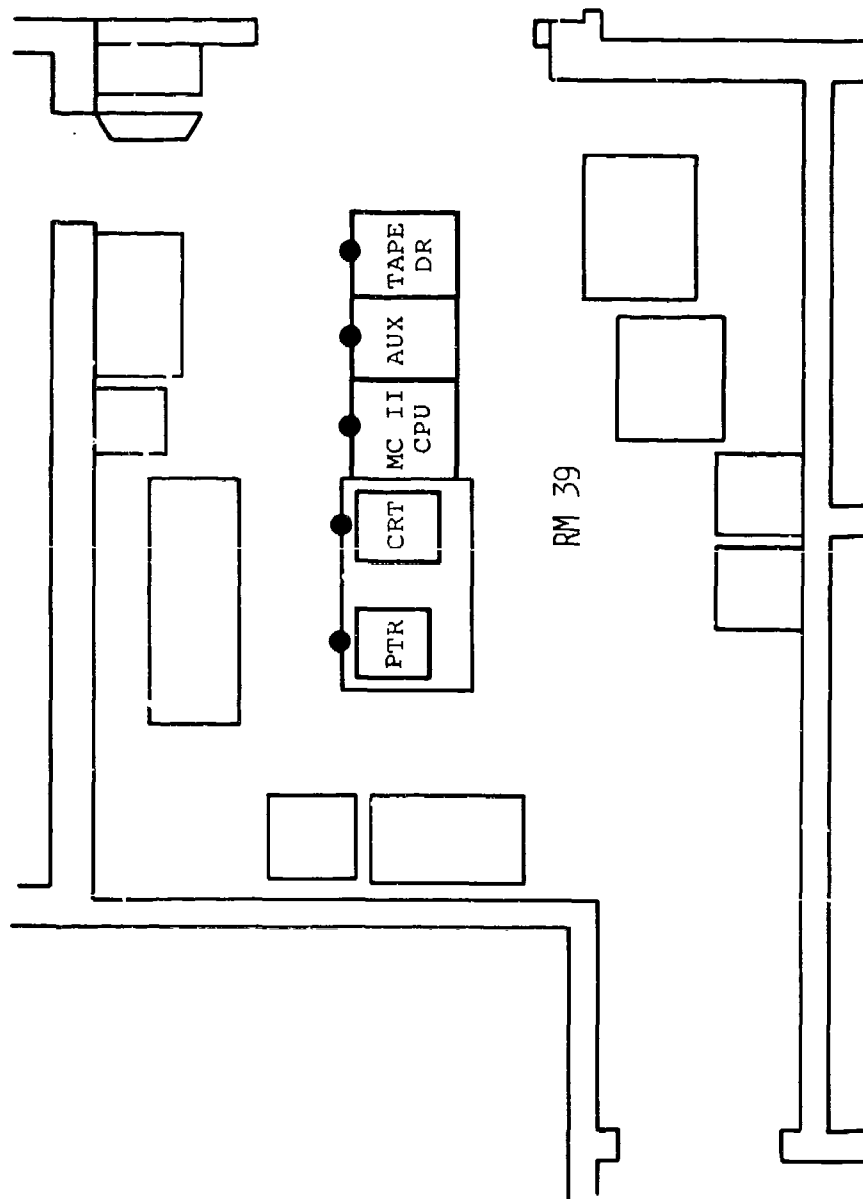
Figure 4-23. MOTIF equipment location, room 39.

paid to the vibration and inertia response under simulated weight conditions. The test conclusions were positive; no serious degradation was detected as a result of the simulated load.

In the spring of 1979, however, a new weight estimate was performed by Itek. The increased weight and distribution change was felt to be of sufficient impact that AMOS could not guarantee that the performance of the telescope would remain unimpaired. In view of the importance of CIS, it was necessary to repeat the inertia tests.

The telescope was loaded to simulate the weight defined in the Itek Interface Document (IID) A-0001-E prior to conducting the tests. In addition to evaluation of mount acceleration and tracking performance, tests were devised to detect gross problems such as bearing seizure as well as effects such as weight induced hysteresis and mechanical deformation which may not be immediately evident.

To minimize the possibility of overlooking a dormant problem, the telescope was used routinely for approximately three months in its maximum weight condition. Operators were instructed to watch for anomalies indicative of a weight-induced phenomenon. The tests were completed in August 1979 and the results are summarized in the following paragraphs.

Mount Model

A mount model was obtained prior to installing the CIS

weights as a reference for future models. Later models were compared to this model to detect elastic and non-elastic deformation of the telescope mount. Column 1 of Table 4-3 gives the reference parameters for the side Blanchard surface of the 1.6 m Telescope.

CIS Simulation

Weights were added to the mount in accordance with IID ITEK-A-0001-E. The C.G.'s and weights used were as close as practical to those specified in this IID with the addition of 80 pounds to the rear Blanchard surface (a revised estimate received by telephone conversation with Itek) and 450 pounds to the side Blanchard surface to simulate a typical measurement package (e.g., AMTA). The polar axis counterweight was increased to balance the additional weight. The total weight added to the telescope for the tests was approximately 9200 pounds. Figure 4-24 (2 sheets) show the location and placement of the added weight.

Fine Balance/Float Check

After installation of the basic weights, it was necessary to fine-balance the declination axis with an additional 100 pounds. The polar axis was fine-balanced by adjusting the position of the adjustable counter-weight. This fine-balancing requires floating each axis and, therefore, tests the ability of the hydraulic system to support the increased load. No mechanical binding was detected during this initial test.

Table 4-3. Equatorial mount model parameters (arcsec)

AMOS parameter file - East mount

Parameter	Before Weights	Weighted	Unweighted
AZ Encoder Bias	1251.8	1249.6	1255.6
X Component of Tilt	-2.7	-7.7	-6.1
Y Component of Tilt	9.1	13.0	5.2
POL Axis EL Error	-20.5	-3.4	-26.9
POL Reticle Reading	0:19:51.3	0:19:51.3	0:19:51.3
AZ Reticle Reading	359:59:33.0	359:59:33.0	359:59:33.0
DEC Encoder Bias	-444.0	-456.9	-423.8
POL Encoder Bias	2690.0	2690.0	2690.0
Inclination	-1.1	-1.1	-1.1
DEC Axis Flexure	-42.8	-42.8	-42.8
DEC Box Flexure	14.5	23.8	-9.2
Collimation Error	15.9	-1.8	11.8
POL Telescope Flexure	32.1	34.8	17.2
DEC Telescope Flexure	17.1	14.7	4.8
Field-of-View	129.6	129.6	129.6
WIKIKAL Collimation	15.3	15.3	15.3
WIKIKAL DEC SAE Bias	-436.0	-436.0	-436.0
DEC Reticle Reading	0:11:0.0	0:11:0.0	0:11:0.0

WEIGHTS

WEIGHTS

WEIGHTS

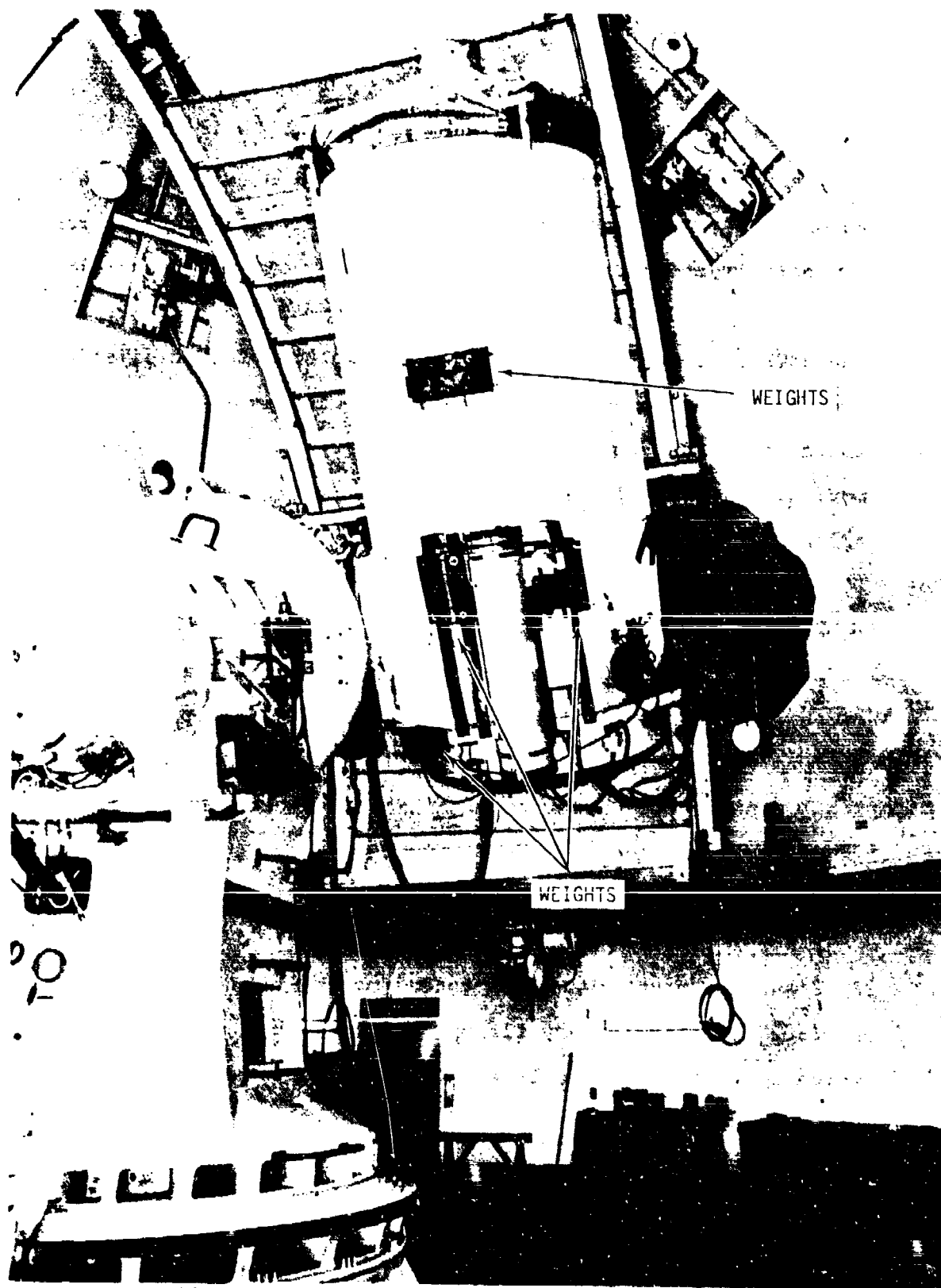Figure 4-24. CIS simulator weights (Sheet 1 of 2).

WEIGHTS

WEIGHTS

Figure 4-24. CIS simulator weights (Sheet 2 of 2).

Acceleration and Tracking Tests

More extensive testing included manual slewing of both axes
through their extremes and computer driving the mount and record-
ing servo system error signals. Simulated CIS-type satellite
passes produced only normal servo errors. Table 4-4 is
the SATPREP computer printout for a simulated fast ballistic
object. The only adverse effect noted with any of these tests
was a decreased acceleration at the start of the telescope
motion. Figure 4-25 shows the servo errors for that simulated
track.

Step Response Test

This test involved computer driving the mount at selected
rates and stepping of the telescope axes into and away from the
direction of motion. Step response was adequate up to the
maximum tested of 2° per second. Figure 4-26 shows the
step response for 1° per second which is closer to the maximum
rates that might actually be encountered during a typical
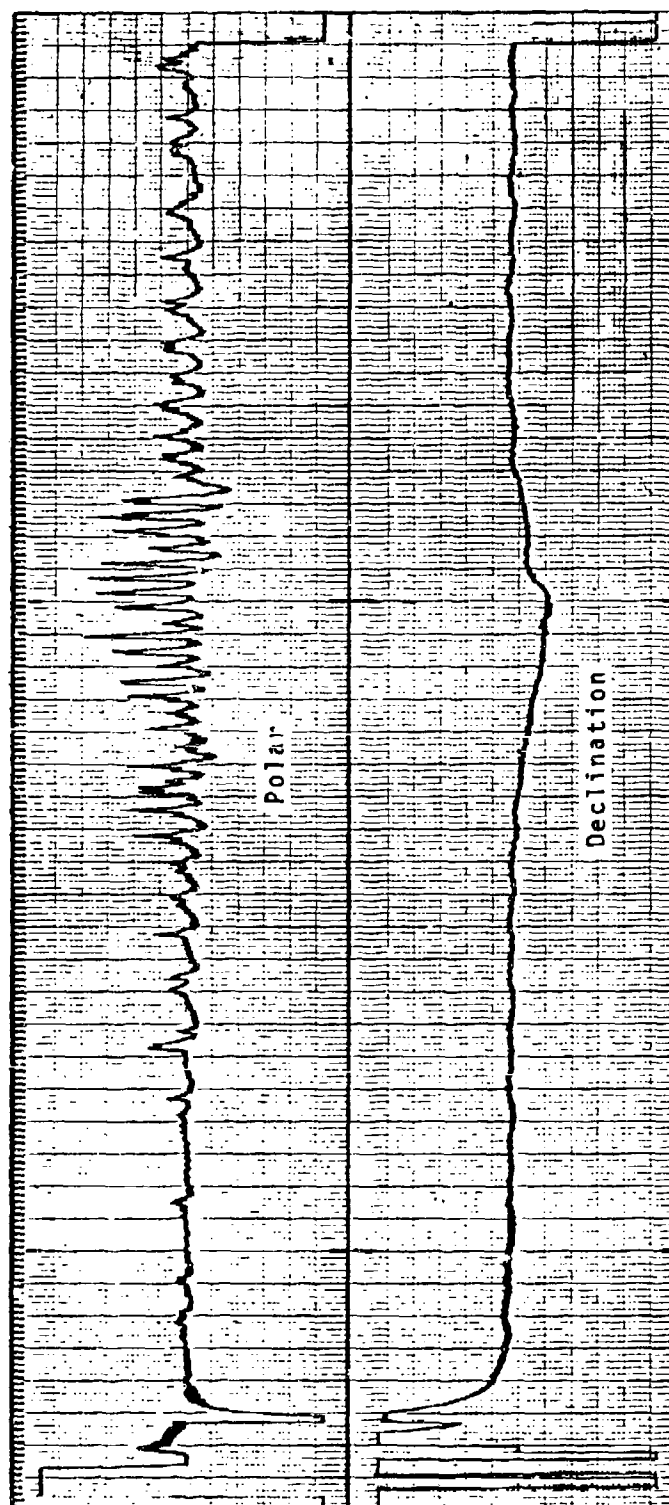satellite pass.

Mount Model

Another mount model was taken for the side Blanchard
surface to determine any flexures induced by the additional
weight. Column 2 of Table 4-3 shows the Mount Parameter
File for this model.

Extended Testing

After the initial tests, the mount was used routinely for

Table 4-4.   1.6 meter inertia test SAMPREP for simulated satellite track.

MOUNT AZ SAE   C244:57 = 08104:56

UT	RANGE KM	AZ	EL	PCL	DEC	PVEL	DVEL		PHASE ANGLE
20:56:0 0M	1053	271.6	10.2	80.6	4.0	-0.12	0.05	LIT	80
20:56:10	985	271.6	11.6	79.3	4.6	-0.13	0.05	LIT	81
20:56:20	916	271.7	13.1	77.9	5.1	-0.15	0.06	LIT	83
20:56:30	848	271.7	14.9	76.3	5.8	-0.17	0.07	LIT	85
20:56:40	781	271.8	16.8	74.4	6.5	-0.20	0.08	LIT	87
20:56:50	715	271.9	19.1	72.3	7.4	-0.23	0.09	LIT	89
20:57:0	649	272.0	21.8	69.8	8.3	-0.28	0.10	LIT	92
20:57:10	585	272.1	25.0	66.7	9.5	-0.33	0.12	LIT	95
20:57:20	522	272.3	28.9	63.0	10.8	-0.42	0.15	LIT	99
20:57:30	463	272.5	33.8	50.3	12.4	-0.52	0.18	LIT	104
20:57:40	407	272.8	39.9	52.3	14.4	-0.68	0.21	LIT	110
20:57:50	356	273.3	47.8	44.4	16.6	-0.90	0.24	LIT	118
20:58:0	314	274.2	58.0	34.1	19.0	-1.18	0.24	LIT	128
20:58:10	283	276.4	70.7	20.7	21.2	-1.49	0.18	LIT	141
20:58:20	269	292.3	85.3	4.7	22.4	-1.67	0.04	LIT	156
20:58:22C	268	325.7	87.8	1.4	22.5	-1.68	0.01	LIT	159
20:58:30	273	82.4	78.8	348.1	22.0	-1.61	-0.13	LIT	171
20:58:40	295	87.6	64.8	333.1	20.1	-1.35	-0.23	LIT	174
20:58:50	331	89.0	53.2	321.1	17.7	-1.05	-0.25	LIT	162
20:59:0	377	89.6	44.1	311.9	15.3	-0.80	-0.23	LIT	153
20:59:10	436	90.0	37.0	305.0	13.1	-0.61	-0.20	LIT	146
20:59:20	488	90.3	31.5	299.6	11.3	-0.47	-0.17	LIT	140
20:59:30	545	90.5	27.1	295.4	9.8	-0.38	-0.14	LIT	136
20:59:40	613	90.6	23.5	292.0	8.5	-0.31	-0.12	LIT	132
20:59:50	677	90.7	20.5	289.2	7.5	-0.25	-0.10	LIT	129
21:00:0	743	90.8	18.1	286.9	6.5	-0.22	-0.09	LIT	127
21:00:10	810	90.9	15.9	284.9	5.8	-0.19	-0.07	LIT	124
21:00:20	878	91.0	14.1	283.1	5.1	-0.16	-0.07	LIT	123

10-656

Figure 4-25. 1.6 meter inertia test simulated satellite track servo errors.

5 seconds

1 arcminute
East

1 arcminute
West
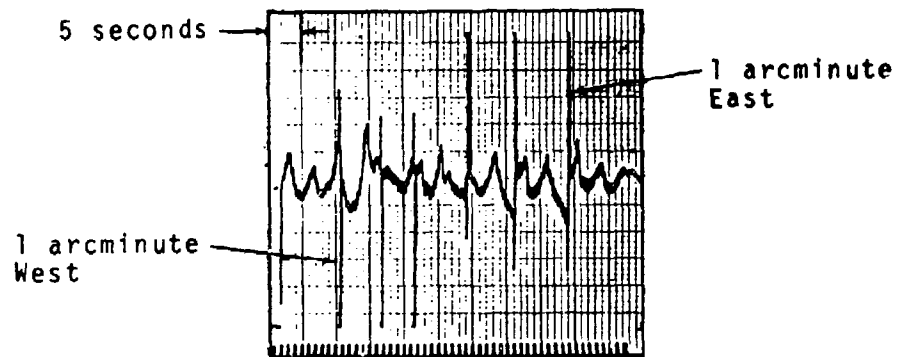
Polar
(1°/second East to West)

5 seconds

1 arcminute
South

1 arcminute
North
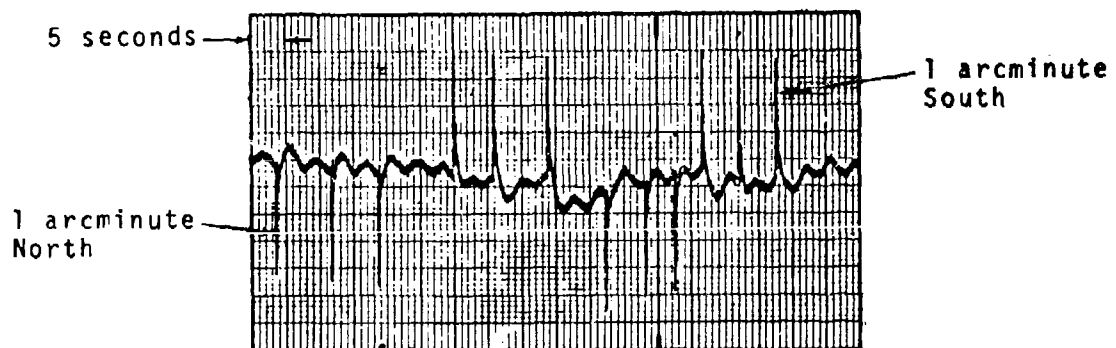
Declination
(1°/second North to South)

10-657

Figure 4-26.   1.6 meter inertia test step response servo errors.

approximately three months. Missions included high elevation fast satellites, routine space object identification, classical imaging, and atmospheric data gathering. The telescope operators were instructed to be alert for any unexplained problems and to log them. No problems were encountered that were attributed to the additional weight.

Final Mount Model

The final test was to model the telescope after the weights were removed. This new model would help identify any gross non-elastic effects. The mount parameters are shown in Column 3 of Table 4-3. Some elastic effects are readily noticeable, such as polar axis elevation error. Changes in declination box flexure and declination telescope flexure are probably an effect of a varying declination encoder bias.

Conclusion

The tests performed indicate that the 1.6 m Telescope complex will perform satisfactorily when loaded with CIS hardware in accordance with IID-ITEK-A-0001-E.

4.3.3.2 Classical Imaging Data Base

The classical imaging program being conducted during Phase IV has two basic goals:

1) Development of a classical imaging data base, augmented by atmospherics data (see Section 4.3.3.3), to aid in the evaluation and optimization of the DARPA compensated imaging system when it arrives at AMOS in 1980;

2) SOI support for ADCOM and other DARPA approved users.

Three specific tasks were included in the 1978 and 1979 efforts in addition to the SOI support.

First, a standard AMOS Mission Instruction and Operation Plan (MIOP #025) was prepared and submitted to RADC for approval (CDRL 002). This document describes the hardware, operational procedures and data reduction required to support a classical imaging mission.

Second, a Classical Sensor Package (CSP) was designed, fabricated and tested by AERL. This effort was completed and documented in 1978.

Third, accumulation of data for the CIS data base was then initiated and continued through 1979.

The exceptional capability of the 1.6 m Telescope and the CSP were clearly demonstrated by numerous satellite and double star images which were collected during 1979.

Considerable effort was devoted to obtaining high quality images of the failing SKYLAB satellite. To support this effort, an investigation was made into the possibility of extending visual observation time by:

1) laser illumination on full-night passes with no solar illumination (see Section 4.9); and

2) daytime imaging.

Both of these techniques have proven feasible and highly effective. Calculations indicated that during the daytime SKYLAB should appear as a $m_v = +1.0$ star if unresolved (e.g.,

with a low power telescope) and as bright as $m_v = +3.5$ per pixel on the 1.6 m Telescope System. Experiments to observe stars in the daytime with the 1.6 m Telescope demonstrated the need for optical baffles to reduce the effects of stray light. The original baffles delivered by Boller & Chivens were installed and enabled the daytime observation of a $+6 \, m_v$ star. It was additionally determined that further improvements could be gained by the future development of a more sophisticated baffling system.

The first attempt at daytime imaging was successful despite an extended layer of cloud cover and poor sun-object geometry. The 13 March observation of SKYLAB resulted in a resolved image, clearly showing object orientation.

A second attempt on 14 March, while showing the existence of an image, appeared much less sharp. Secondary observations on stars indicated that the seeing conditions were probably inferior to those of the previous mission.

Examples of the daytime images are shown in Figure 4-27. These images of SKYLAB were acquired at 7:36 a.m. on 30 April 1979, under full daylight conditions and exhibit excellent gray scale and edge definition.

It appears possible that daytime imaging may not only compete with the image quality obtained at night but could possibly excel due to the daytime existence of backscattered
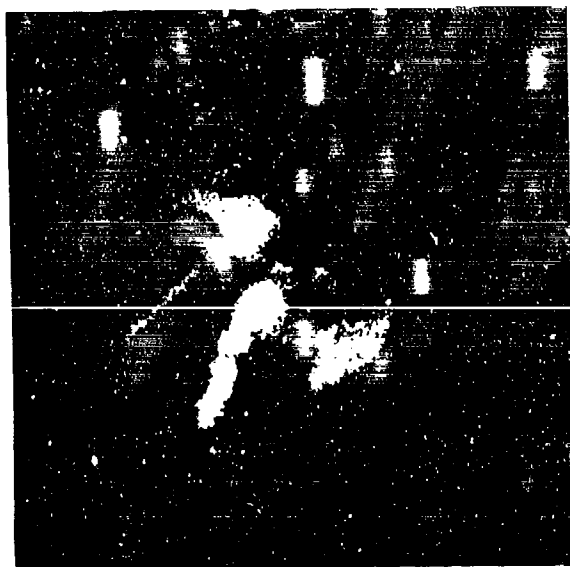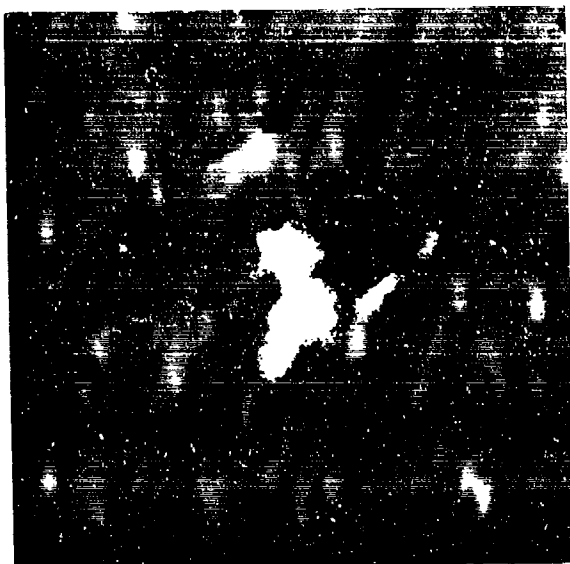
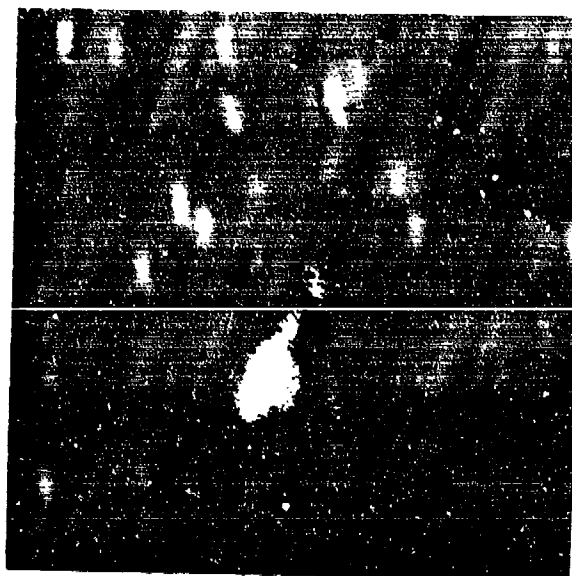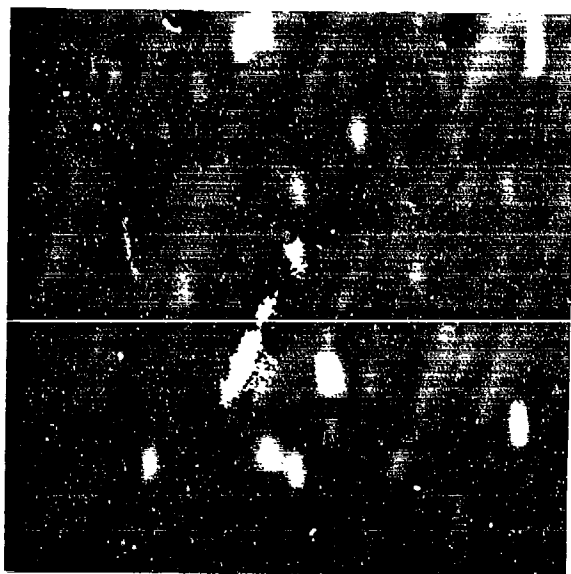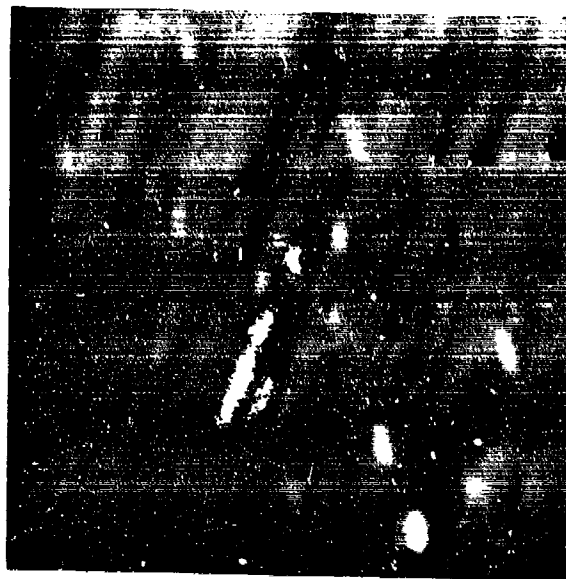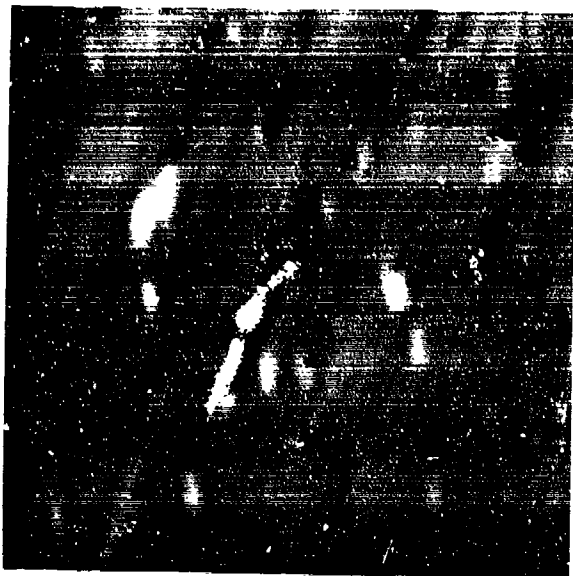Figure 4-27.   Daytime images - SKYLAB (Sheet 1 of 2).

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Figure 4-27.   Daytime images - SKYLAB (Sheet 2 of 2).

sunlight from the earth which serves to fill shadow areas on
the target.

Additional examples of satellite images taken in 1979 are
shown in Figures 4-28 through 4-30.

As part of the classical imaging program, a coordinated
effort was begun to obtain Seeing Monitor data during the
period in which the photographs are taken. These efforts have
met with only limited success. Although it has been possible
to obtain r_o measurements during approximately the same time
period in which the photographs are taken, the requirement for
using bright stars which do not necessarily fall along the path
of the satellite track and the relatively long integration
times normally used with the Seeing Monitor tend to render all
correlations questionable. Never the less, the trend does
exist in which the highest quality images are taken on missions
in which the r_o readings are high (12 to 16 cm). A technique
for recovering the instantaneous seeing conditions directly
from a satellite using the Fourier transform of a chopped image
has been under investigation and may result in a viable alternate
system to accomplish the desired objectives. Further investi-
gation into this technique will continue in 1980 as time permits.

In addition to satellite photographs, the CSP has been used
to collect unresolved images of double stars with separations
from 0.8 arcseconds to over ten arcseconds. The closely spaced
stars provide a means of estimating the seeing conditions while

This series of direct to film images
was taken with the AMOS 1.6 meter
Telescope having a focal length of
25.1 m.

Object 10561   12 May 79 UT
CLI-008

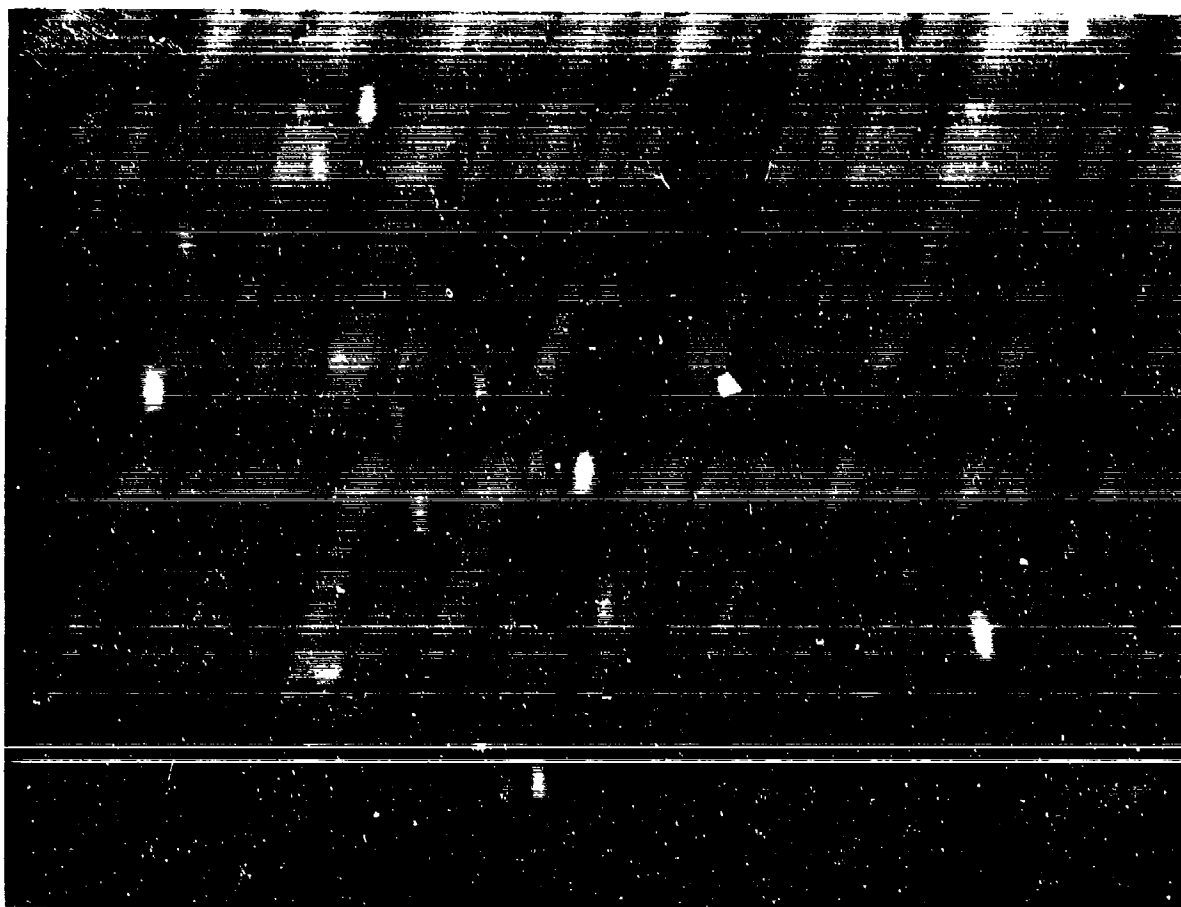Range at
Culmination   -   711 km
Elevation   - 60.9^{o}
Frame Rate   -   10 Frames per sec
Exposure Time   -   40 msec
Camera   -   Lo-Cam
Filter   -   #21 Wratten
Illumination   -   Solar

Figure 4-28.   Satellite images (Sheet 1 of 2).
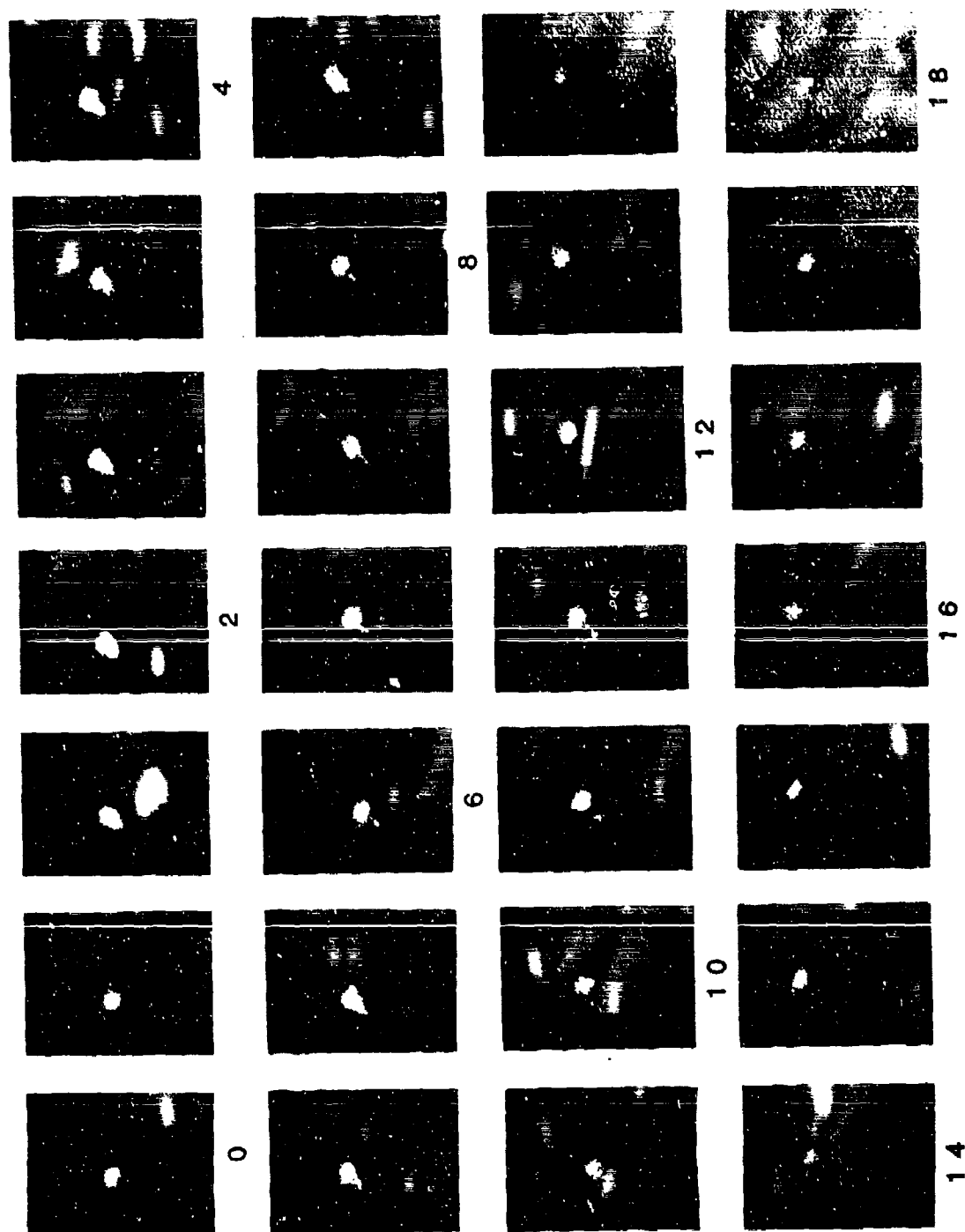
ELAPSED TIME IN SECONDS
RANGE AT CULMINATION 711 km.

Figure 4-28. Satellite images (Sheet 2 of 2).

This direct-to-film image was obtained with the Classical Imaging
Package on the AMOS 1.6 m Telescope which has a focal length of
25.1 meters. A 16 mm LoCam film camera, operated at 7 frames per
second with a tri-exposure shutter, was used to obtain the original
film.

CLI #14
Object #11449   21 Dec 1979

Elevation   — 80°
Range   —   533 km
Exposure   —   36 msec
Frame Rate   —   7 FPS
Filter   —   21 Wratten
Illumination   —   Solar
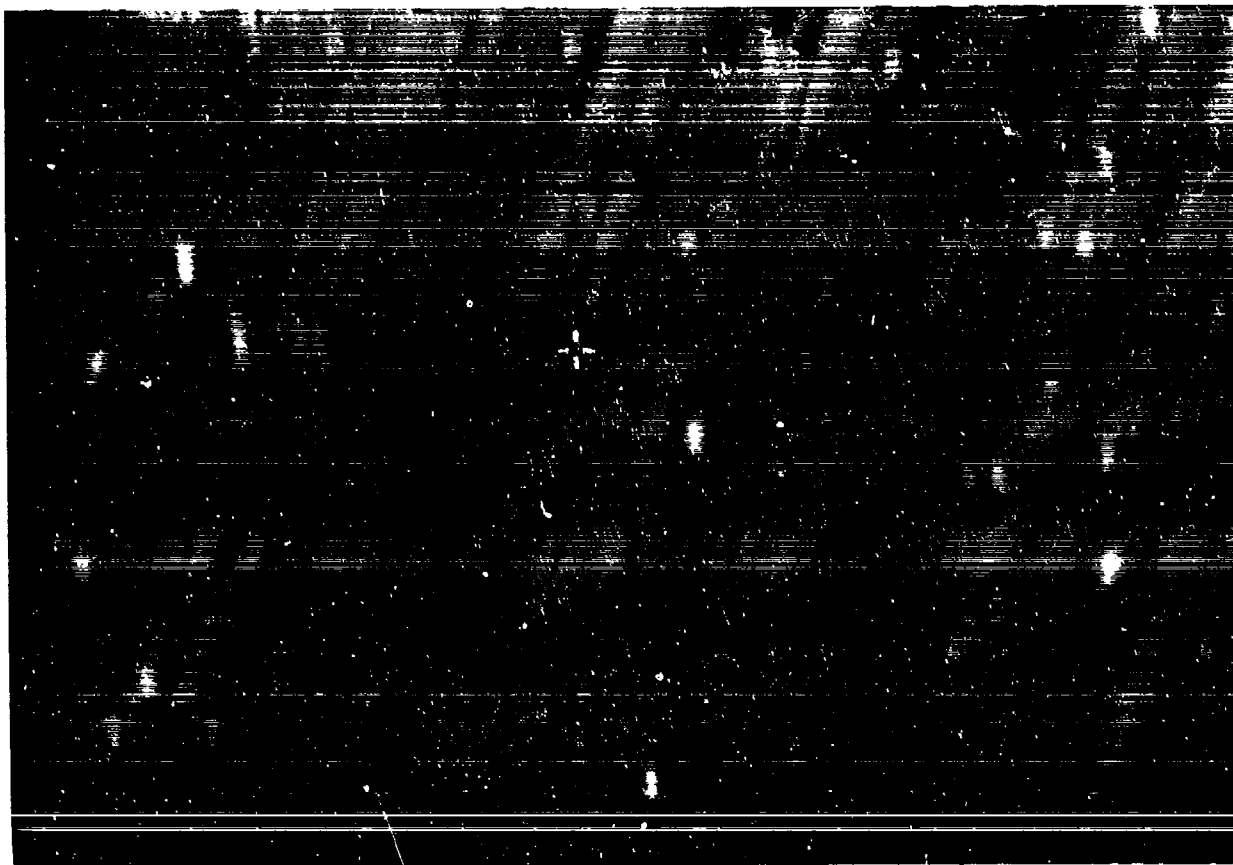
Figure 4-29.   Satellite image.

This direct-to-film image was obtained with the Classical
Imaging Package on the AMOS 1.6 m Telescope which has a
25.1 m focal length. A 16 mm LOCAM framing camera, operated
at 8 fr/sec or 12 fr/sec with a tri-exposure shutter, was
used to obtain the original films.

| Print | 10860 | 25 Jan 79 UT |
| CLI-002-661 | | |

|		
Range	–	666 km
Elevation	–	72°
Exposure time	–	1/24 msec
Frame rate	–	8 fr/sec
Filter	–	Wratten 21 (orange)
Angular dimensions	–	2.09 sec x 2.21 sec

6 March 1979/1

Figure 4-30.   Satellite image.

short exposure photos of the wider spaced stars provide a
measure of the isoplantic patch size. Examples of these double
star images are presented in Figures 4-31 through 4-34.

As a result of the satellite image data collected during
this program, a paper entitled "High Resolution Imagery at
AMOS" was prepared and presented at the NORSIC 11 meeting in
August 1979. The paper contains samples of several types of
imaging data gathered under a variety of illumination conditions.
Included are images acquired at twilight with a dark sky
background, laser illuminated images when the object was in the
earth's shadow and images obtained under full daylight conditions.
The paper carried the following abstract:

High resolution images of selected
foreign and domestic satellites,
recently obtained with the diffraction
limited AMOS 1.6 m Telescope, are
presented and discussed for possible
use as a method of tactical space
object identification. The data
includes direct-to-film images
of solar-illuminated targets taken
during both twilight and daytime
site conditions. Included also are
ISIT (video) images of SKYLAB
illuminated by a ruby laser while
the vehicle was in the earth's
shadow. A brief description of the
system hardware is presented.
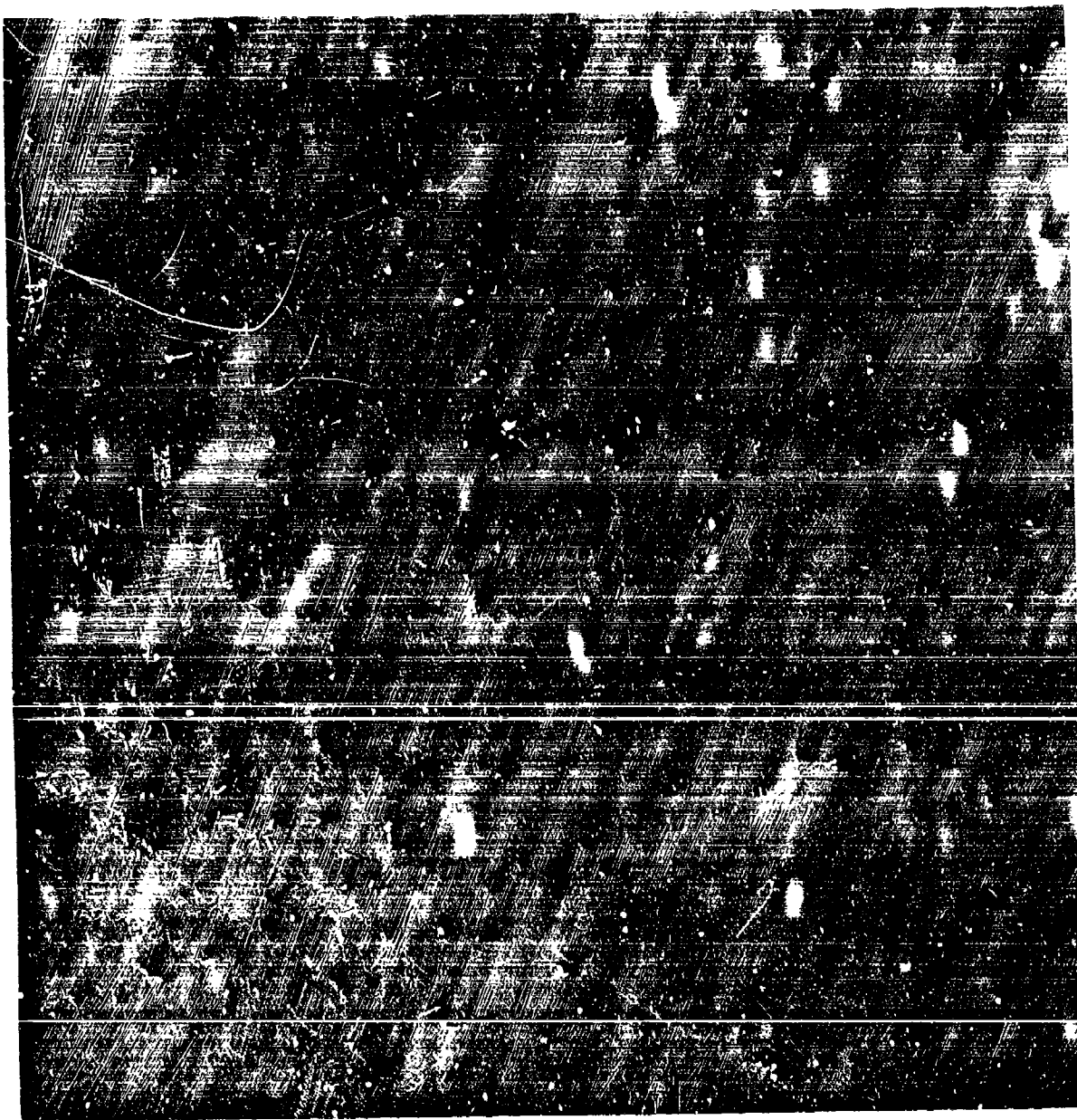
ASN 41   m$_v$ 2.61 - 3.80   Sep. 4.3 arcseconds
            72 el.   21 Wratten filter
            45 msec exposure   1 May 79

Figure 4-31.   Double star image.
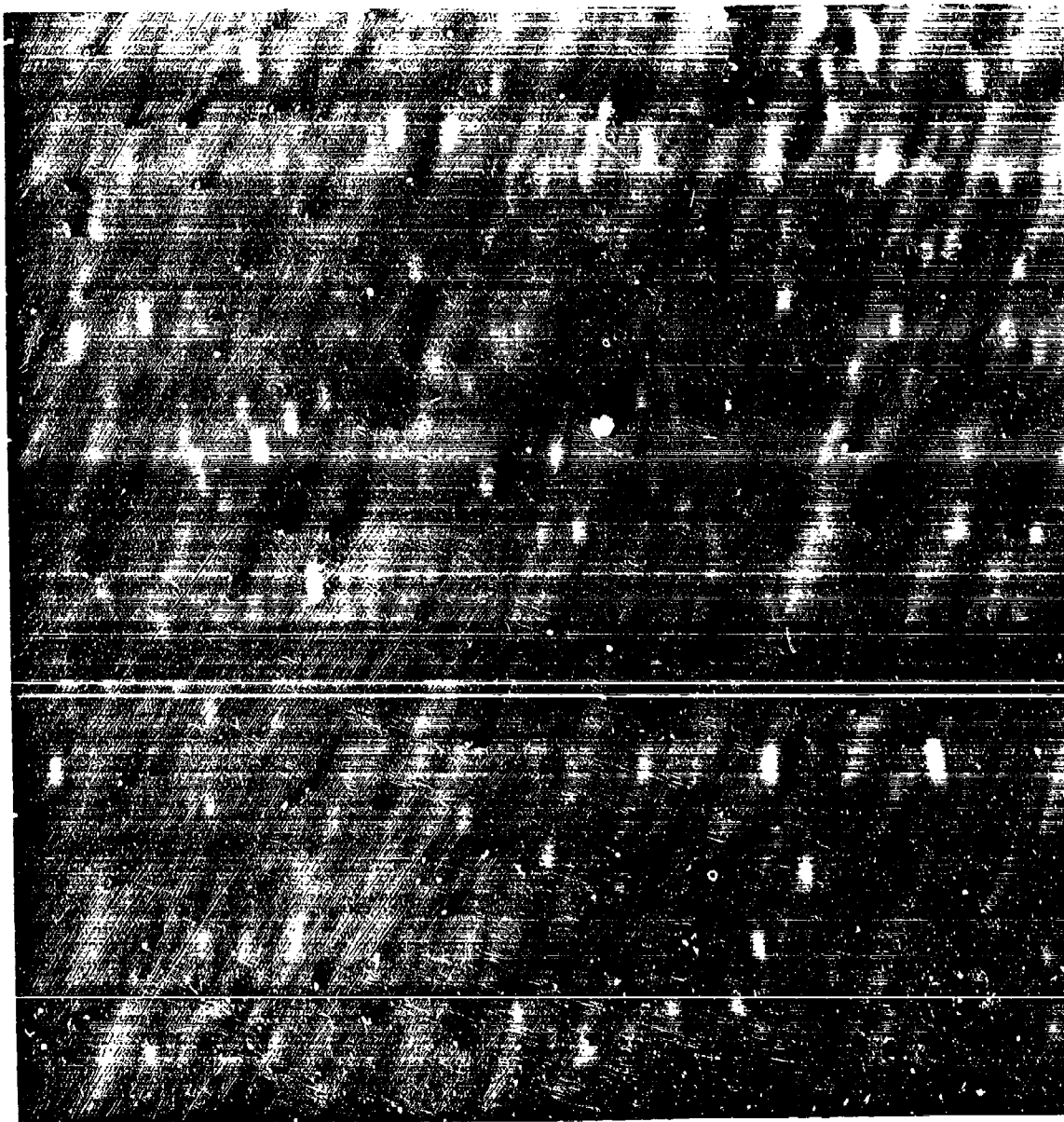
ASN 708 m_v 4.0 - 5.0   Sep. 2.9 arcseconds
          73 el.   21 Wratten filter
          40 msec exposure   1 May 79

Figure 4-32.   Double star image.
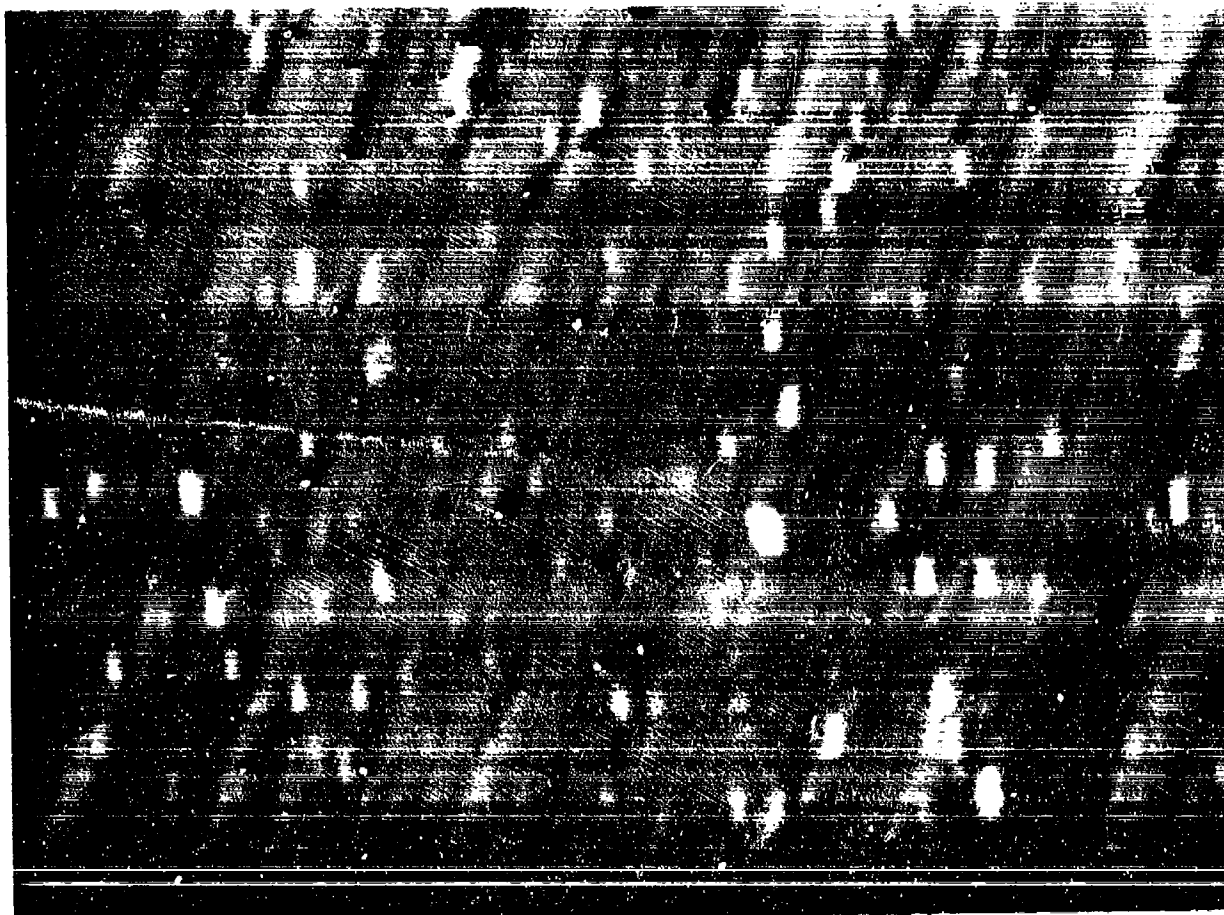
This direct-to-film image was obtained with the Classical Imaging
Package on the AMOS 1.6 m Telescope which has a 25.1 m focal length.
A 16 mm LOCAM framing camera, operated at 8 fr/sec or 12 fr/sec
with a tri-exposure shutter, was used to obtain the original films.

Print	ASN 18	25 Jan 79 UT
ASN 18	Epsilon Arietus	
	GC 3582	

Elevation	–	87°
Magnitudes m_v	–	6.00 & 6.40
Separation	–	1.5 arcseconds (1952)
		1.48 arcseconds (film measurements)

6 March 1979/2

Figure 4-33.   Double star image.
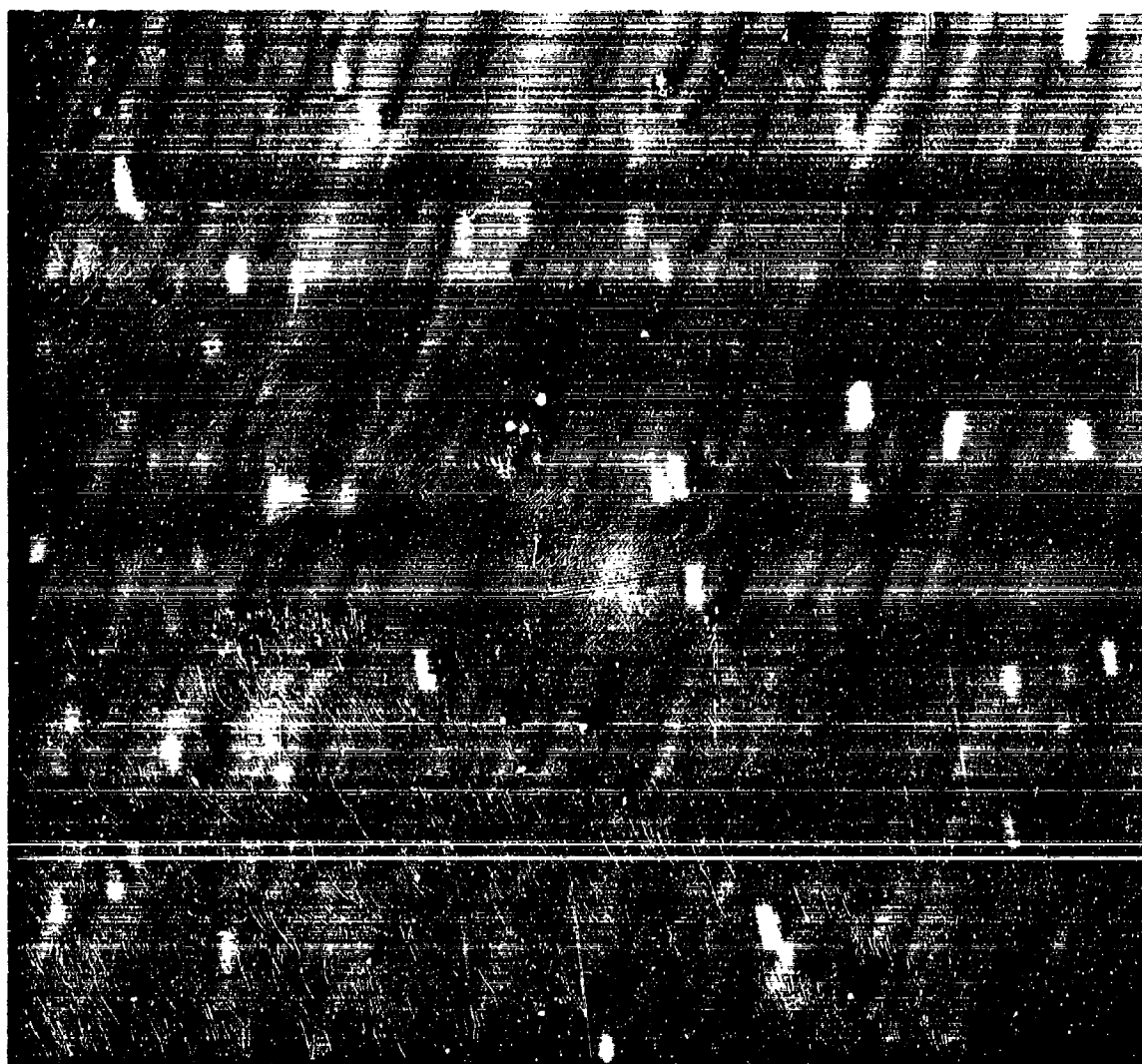
This direct-to-film image was obtained with the Classical
Imaging Package on the AMOS 1.6 m Telescope which has a
focal length of 25.1 meters. A 16 mm LoCam film camera,
operated at 7 frames per sec with a tri-exposure shutter,
was used to obtain the original film.

ASN 8559	Zeta Aquarious	28 Nov. 79 UT
Elevation	–	63 degrees
Visual Mag.	–	3.66 / 3.42
Separation	–	1.77 arcseconds
Exposure	–	4 msec

Figure 4-34. Double star image.

4.3.3.3 Atmospherics Data Base

During the AMOS Phase III program, an array of atmospheric instrumentation was installed at the Observatory. The implemented systems were:

1) Seeing Monitor: an instrument, located on the rear Blanchard surface of the 1.6 m Telescope, that measures r_o, the correlation scale length;

2) Star Sensor: an instrument, located in a separate dome at the northeast corner of the Observatory, that provides profiles of C_N^2;

3) Acoustic Sounder: an instrument that measures C_N^2 to 300 m altitude;

4) Microthermal Probes: two systems, consisting of three probes each, which measure C_N^2 at one level (18 m);

5) Routine Meteorological Sensors: instrumentation that measures wind speed, wind direction, temperature, dew point and barometric pressure;

6) All-Sky Camera: a camera that records cloud cover on a 24-hour schedule.

By the end of the Phase III program all of this instrumentation was functioning and had been used to obtain a preliminary atmospheric data base. One of the main purposes of this data was to aid in making critical design decisions for CIS hardware.

During the first few months of 1978, emphasis shifted towards making the hardware operational, accomplishing minor upgrades and fully documenting the systems.

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By the fall of 1978, the atmospherics instrumentation was ready to be used for its primary goal - accumulation of an extensive data base. Figure 4-35 shows a schematical representation of the atmospheric system as it exists in late 1979.

Atmospheric Operations Summary

Although the atmospheric system is considered to be operational, a major portion of the 1979 effort was devoted to system maintenance and calibration. The atmospheric system represents a complex array of engineering and scientific instrumentation prototypes which have been found to require more than routine maintenance and in which a calibration schedule has not been established. Indeed, by the very nature of the statistically variable data which is gathered with the instruments, it is not always apparent when systems are out of calibration or that maintenance is actually required. Performance discrepancies are at times so subtle that they are uncovered only in the data reduction process where cross correlation between instrument outputs is possible. The time lag between data collection and reduction aggravates the situation and, perhaps of more importance, data reduction is performed at a facility (RADC) which is remote from the data collection site and by different personnel so that the immediate and direct feedback that is so necessary to a highly successful scientific experiment is lost.

Never the less, during 1979, the atmospheric program produced
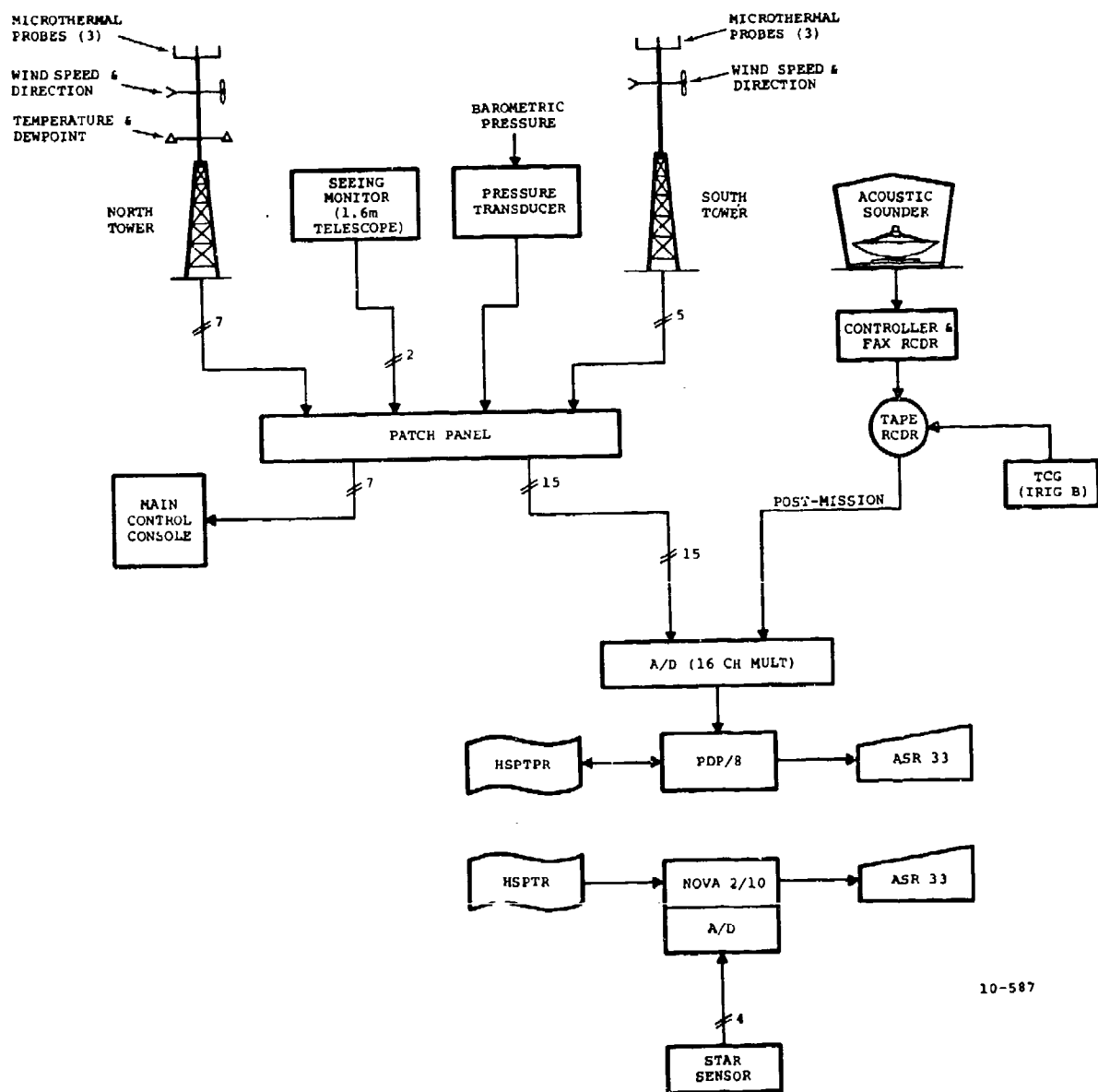
Figure 4-35.   Atmospheric system.

twenty data packages which were validated at AMOS and forwarded
to RADC. In addition, scientific personnel at AMOS separately
performed atmospheric related experiments. The following
discussion on image wander is an example of these experiments.

Image Wander Measurements

Star image wander was observed in May of 1979 with view to
determining the temporal distribution of atmospheric refractive
structure which will alter the apparent line-of-sight of a
high resolution image tracker. Observations of stars at 83°,
40° and 11° elevation were made with the aid of the Seeing
Monitor mounted on the 1.6 m Telescope. This instrument
outputs a voltage proportional to each of two orthogonal
components of point image decentration (wander) with respect to
an internal reference line-of-sight. The Seeing Monitor
employs S-20 cathodes and a bandpass filter restricting the
measurement to between 0.58 and 0.62 μm. The voltages are
produced with 200 Hz information bandwidth and were recorded on
analog tape together with telescope shaft encoder error signals.
The latter signals, in principle, permit unwinding the effects
of telescope disturbance torques due to possible wind buffeting.
In practice, it turned out that the pointing error signals were
too minute to retrieve from tape with any confidence so automatic
data correction was abandoned and the plots presented here
represent Seeing Monitor output only.

Atmospheric affected distortion of star images has been

qualitatively characterized by astronomical observers as "image dance" and "image squirm" (or "speckle"). The first named is produced by structure of the order of or larger than the observing pupil; the latter by refraction features smaller than the pupil. Taken together, the two limit what has been quantitatively measured as long exposure 'seeing'. The Seeing Monitor measures both instantaneous image size and position independently. Because the AFWL is primarily interested in long wave propagation, we recorded only the wander histories for this analysis.

Gross wander statistics for two different zenith distance stars are presented in Figure 4-36, which shows probability density and cumulative distribution derived from α Leo and β Gem seeing monitor wander records. The histograms represent the distribution of 1675 equally spaced samplings of wavefront tilt about the nominal LOS offset observed during ≈ 195 seconds.

The steady state wander voltages recorded on tape necessarily include offsets produced by lack of correspondence between the television finder reference fiducial and the SM field-of-view center, plus analog recorder and playback misadjustments (zero-volt frequency, tape speed error and discriminator alignment). These offsets have no physical significance and use up the dynamic range of the analyzer. When gain is reduced to accommodate the dc component, the
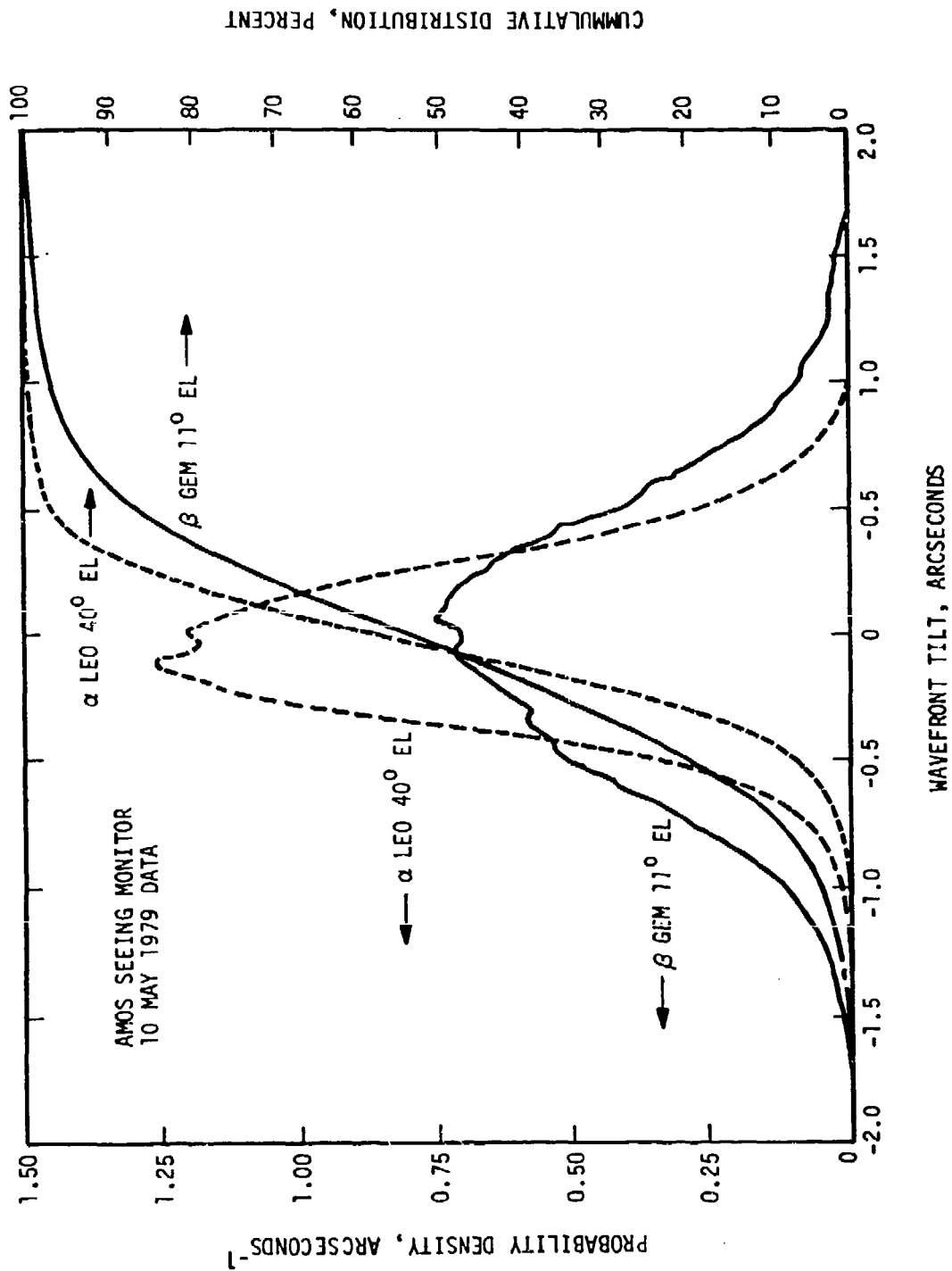
Figure 4-36. Gross wander.

display is compacted and less resolvable. For this reason, the
playback system was ac coupled and an artifical zero tilt
reference, corresponding to the average dc voltage, is included
in the processed data. The low frequency corner occurs at 0.5 Hz.

The density values in Figure 4-37 represent populations
per arcsecond. During the course of observation, α Leo and β Gem
set through 0.014 and 0.35 airmasses, respectively.
If automatic refraction corrections were not incorporated into
the 'sidereal' pointing schedule, a gradual offset would
accumulate in the dc record reflecting the change in refractive
index. In particular, if the atmospheric model used to generate
the correction were inappropriate, a (smaller) dc offset would
accumulate. AC coupling also eliminated distortion or skewing
of the distributions from this cause. Additional data obtained
at 83° elevation (α Boo) is not shown because it is nearly
indistinguishable from α Leo. The distribution of tilts
observed for this star is also biased in favor of negative tilts,
although Boo was rising, not setting, during the observation.

The measured frequency distribution of nder statistics
is shown in Figure 4-37. The spectral density of tilt observed
at low elevation is approximately 0.5 arcseconds per $\sqrt{Hz}$ near
1 Hz. The difference between 1 and 1.55 airmasses (α Boo
and α Leo) appears to be insignificant. Above 2 Hz, tilt
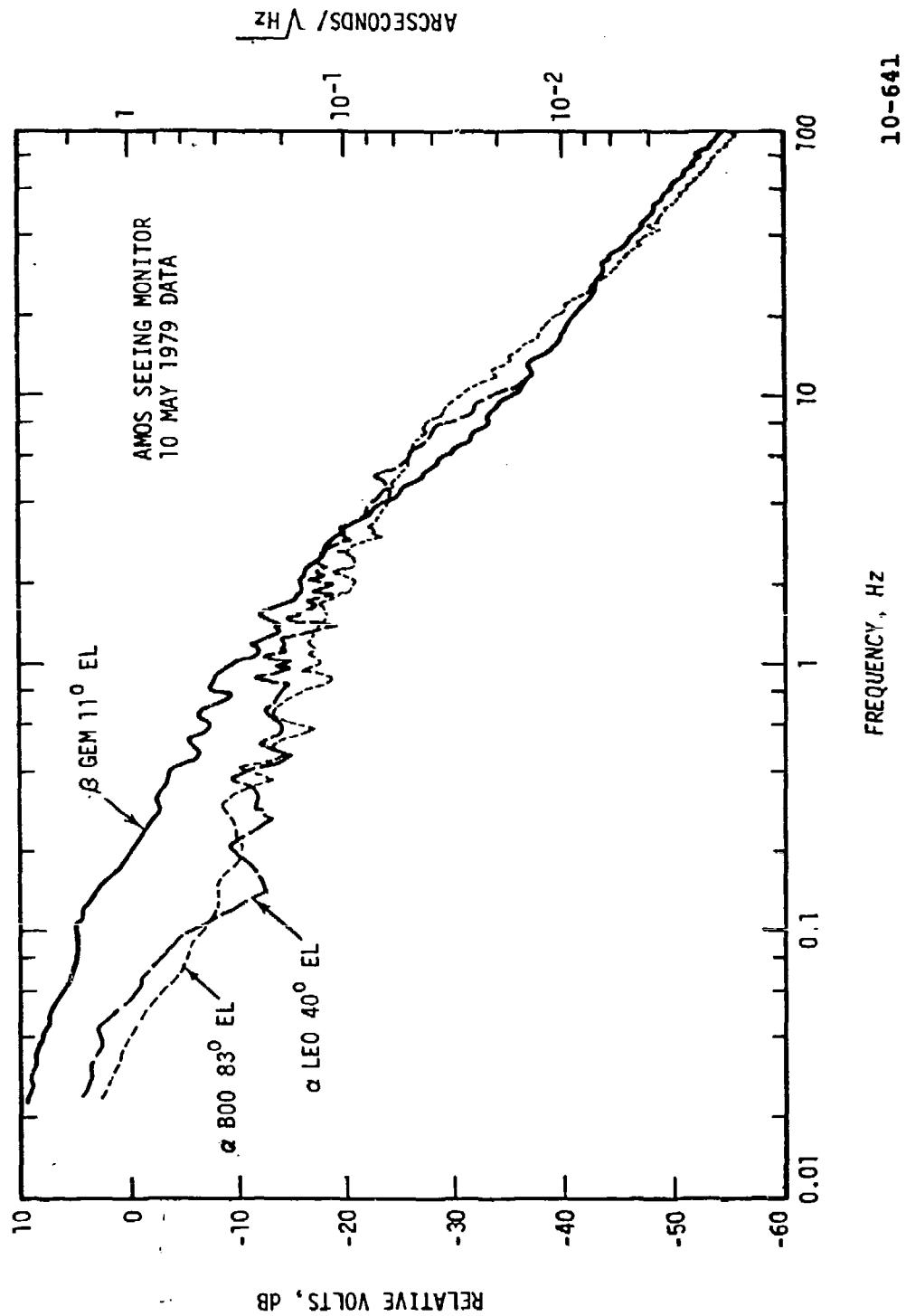density falls off slightly faster than inverse frequency.

Figure 4-37. Frequency distribution of wander statistics.

10-641

From the standpoint of determining image location only, it appears that a $\leq$0.1 second look will freeze atmosphere induced star image dance to well within the diffraction limited performance of the 1.6 m Telescope under excellent seeing conditions with local winds less than 5 mph.

The data described so far represents the polar component of image motion. Declination and polar components are plotted together in Figure 4-38 which serves to illustrate that there is appreciable anisotropy. The cross spectral density distribution, pol related to dec, is plotted in Figure 4-39 for all three observations. If tilt were isotropic, these spectra would correspond to the square of those shown in Figure 4-38.

4.4   AMOS Users Manual

The Phase IV Program includes a one-time revision of the AMOS USERS MANUAL. The revision was originally scheduled to be accomplished in March of 1979. Since the intent of the task is to provide a document that accurately describes AMOS capabilities, it was decided to delay the task for several months. This delay will allow the many hardware changes that are currently being implemented to be incorporated into the document. These changes include:

1)   New Acquisition Telescopes (AATS);

2)   Modifications to the laser ranging system;

3)   Modifications to the B29 secondary;
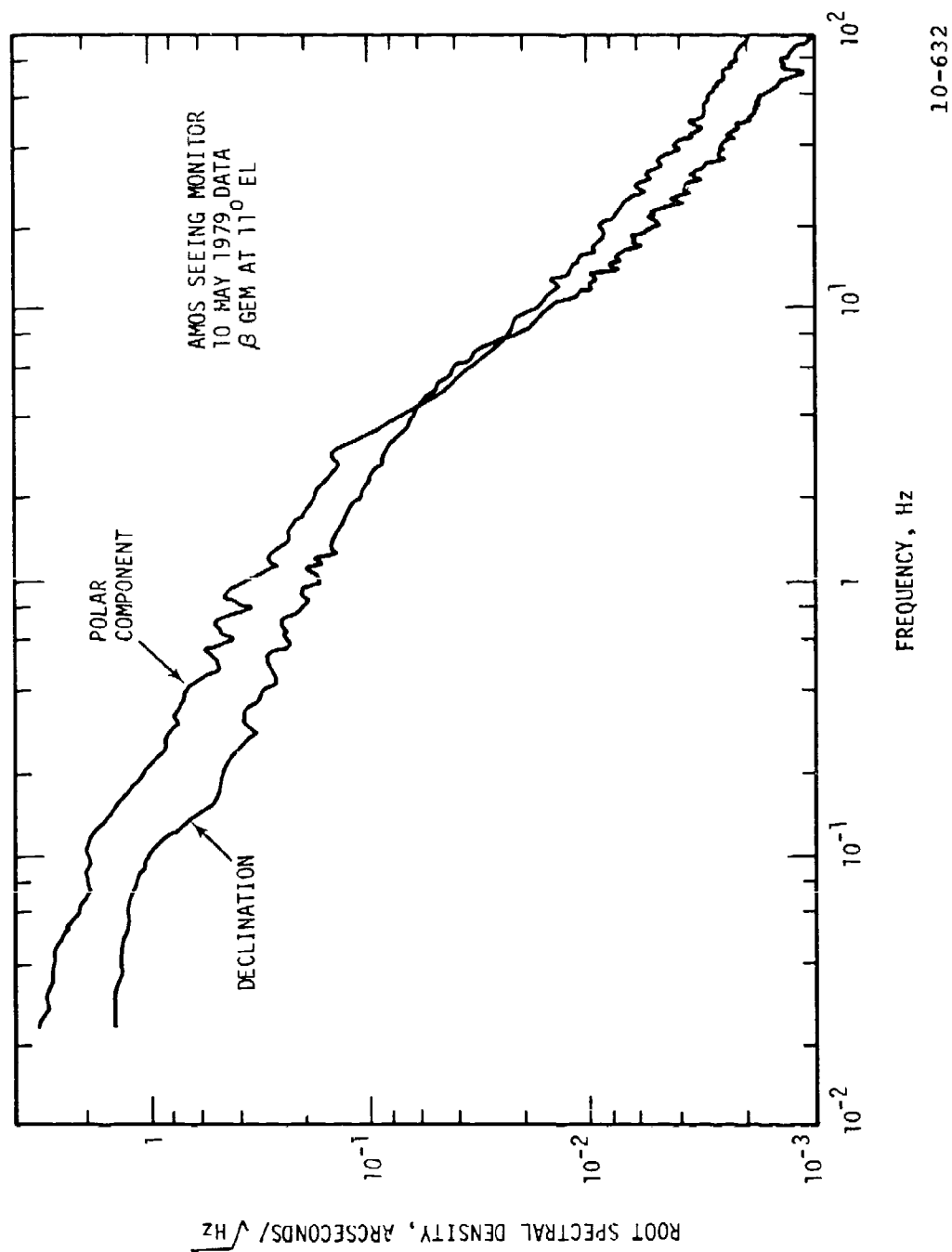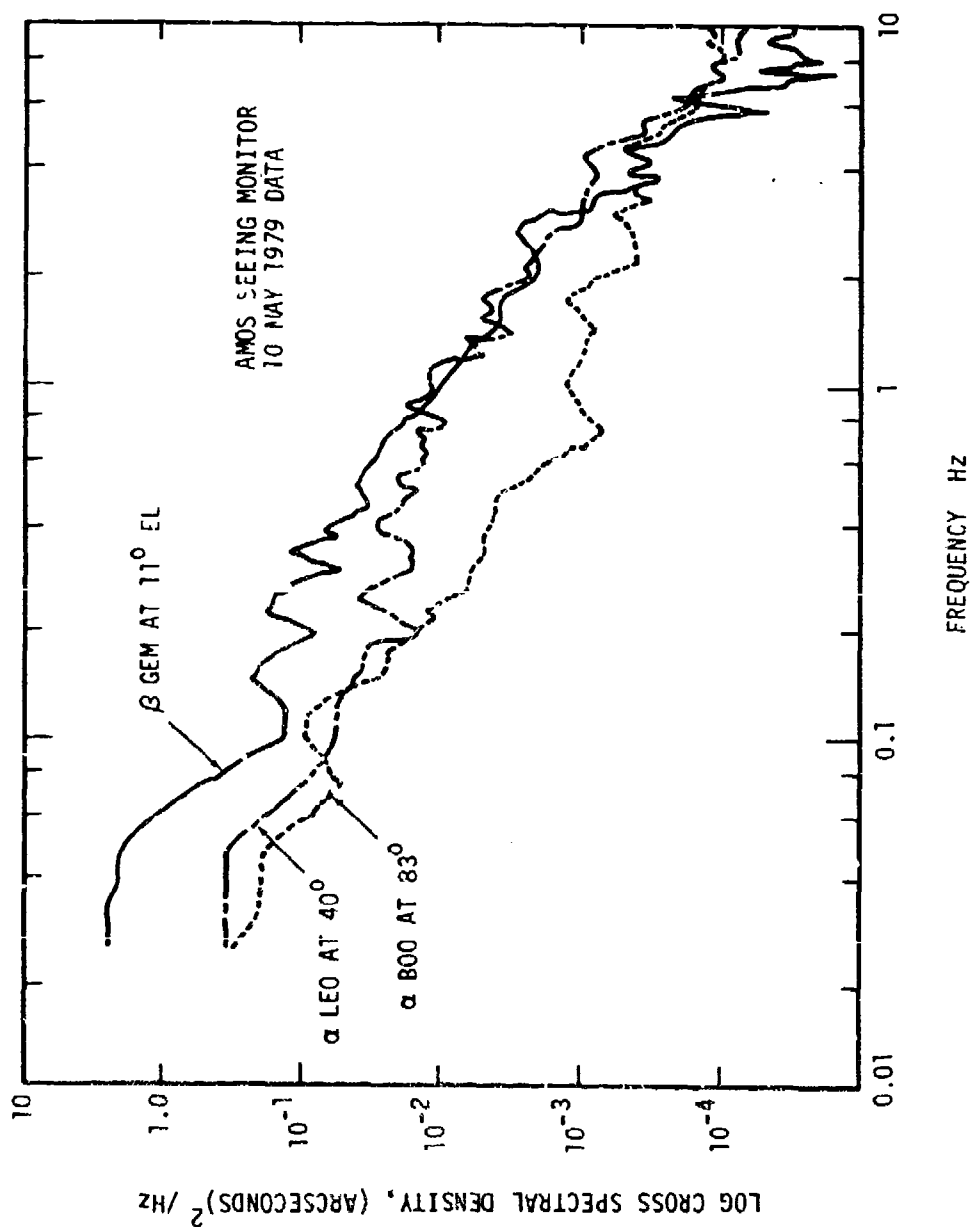
Figure 4-38. Anisotropy of image wander.

10-632

Figure 4-39. Anisotropy - Pol & Dec image wander cross section.

10-639

4)   Modifications to AMTA;

5)   Facility modifications.

Based upon current schedules for the above modifications, a logical time to revise the AMOS USERS MANUAL is May of 1980. The task has accordingly been rescheduled.

4.5   AMOS System Schedule

The AMOS System Schedule (CDRL 006) is published monthly. Its function is that of a management tool which provides current status and near term projection of AMOS activities. The schedule shows events each week for the month preceding and the three months following the report date.   The schedule shows planned and actual events versus time, together with annotations referencing changes to original schedules.   Figure 4-40 shows a typical AMOS System Schedule.

4.6   System Maintenance

To accomplish preventive and corrective maintenance, configuration management and calibration necessary for operation of the AMOS system, AERL conducts a maintenance program in accordance with the AMOS Maintenance Procedure.   (Existing subsystem procedures are revised as required.)

The maintenance program consists of both periodic and corrective maintenance.   All maintenance is performed in accordance with established AMOS quality assurance, safety and logistics procedures.

The maintenance program is conducted by engineering and

Figure 4-40. Typical AMOS system schedule (Sheet 1 of 2).

Figure 4-40.   Typical AMOS system schedule (Sheet 2 of 2).

technical personnel. Both in the periodic and corrective

maintenance areas, engineering personnel ensure that the

maintenance has been completed in such a manner that system

operating characteristics are maintained or improved. Further-

more, corrective maintenance requires that cognizant systems

or sensor engineering personnel be involved from initial

diagnosis through the maintenance and subsequent test function

in all but the most straightforward situations.

Periodic (preventive) maintenance in the form of inspection,

overhaul, lubrication, cleaning, alignment, adjustment and

calibration is performed to assure satisfactory system operation.

The objective is to reduce failures and to maximize operational

availability. All preventive maintenance is performed in

accordance with the master maintenance schedule. Maintenance

activities are scheduled to increase efficiency and to minimize

downtime. Major periodic maintenance activities that result in

loss of operating time are included in the weekly observatory

schedule. During 1979, over six hundred (600) preventive

maintenance inspections were performed.

A calibration laboratory, containing a select group of

working standards, is maintained at AMOS. Working standards

are calibrated at the USAF Precision Measurement Equipment

Laboratory (PMEL) at Hickam AFB for periodic NBS traceability

certification per established schedules. An additional schedule

was generated to allow all test equipment within the facility

to be periodically calibrated to AMOS working standards. This category of equipment is not sent to the USAF PMEL, except those equipments requiring repair or other service beyond the AMOS facility capability.

Corrective maintenance consists of troubleshooting and repair of malfunctioning hardware and software. Following corrective maintenance, performance verification and recalibrations are performed by AERL and, if required, subcontractor personnel under the direction of responsible engineering personnel. Corrective maintenance tasks that exceed the capabilities of on-site personnel and/or support/test equipment utilize original equipment manufacturer field and factory maintenance services and AERL off-site engineering support.

The key element in maintenance reporting and record-keeping is the AMOS Maintenance Report. Each Maintenance Report represents an individual activity and contains: equipment name, date; a brief description of the requirement; corrective action; names of the initiator, implementor and validator; material use; and manhours expended. Selected information from these reports is entered into the AMOS Control Software (ACONS). Each month, ACONS processes this information and outputs Discrepancy Report Status, Discrepancy Report History and Maintenance Accounting Information listings. Periodic maintenance performed is recorded on a Periodic Maintenance Card and is fed into the same ACONS data base. In accordance with the requirements

of CDRL Item 001, the above information is used to generate the monthly Failure Summary Report. During 1979, over 150 Discrepancy Reports were opened and closed.

In accordance with the provisions of the AMOS Configuration Managem nt Plan, AERL identifies and documents the functional and physical characteristics of system configuration items, controls changes to these characteristics and records and reports change processing and implementation.

AERL documents all changes made to AMOS hardware, technical documentation, computer softwa.e and maintenance and operating procedures (CDRL 005). A file of this documentation is maintained at the Observatory and at the AERL Puunene office facility. A computerized index of operation and maintenance manuals, computer programs, specifications and drawings as well as an equipment inventory is maintained as part of ACONS.

Changes to released engineering drawings and specifications are processed, controlled and recorded in accordance with AERL's engineering change procedures.

4.7 Data Library

The AMOS Data Library consists of an area located in the AERL Puunene office facility which contains Operations Reports, annotated real-time and playback chart records, computer-generated plots and history reports, films, voice-time cassettes and other data items obtained in support of DARPA programs. It also

includes areas at the AMOS Observatory reserved for storage of magnetic tapes. The AMOS Data Library shares physical space and the services of one full-time data librarian with the MOTIF program. The library was relocated during 1979 to make room for a new MODCOMP Classic V Computer and expanded in size to accommodate increased storage.

The Phase IV Data Library effort, which began in February 1978 and was completed on schedule in April of last year consisted of the following tasks:

1) Preparation of a Data Control and Access Plan;

2) Establishment of New Tape Recycling Procedures;

3) Generation of a Cross Reference File;

4) Evaluation of the level of accumulation of data for Phase IV; and

5) · Evaluation of the internal files for storage of memoranda and data and generation of recommendations for improvement.

4.8   Data Reduction

The Phase IV data reduction effort consists of two tasks. The first is the qualification and/or reduction of raw data obtained in support of DARPA-sponsored or approved programs. The nature and extent of this task varies with each mission and is dependent on the type of raw data, the level of qualification and/or reduction required to satisfy DARPA objectives,

and the mission frequency. A major portion of this task is related to Compensated Imaging (CI) and, initially, to data for the CI data base. With respect to the CI data base, the reduction/qualification consists of the evaluation of photographs obtained with the Classical Sensor Package and validation and transmittal of data generated from the Atmospherics Program including reduction of the All-Sky Camera films.

During the year, on-site discussions were held with personnel from RADC concerning the optimum content of Atmospheric Data Packages and validation procedures. As a result of these discussions and feedback from RADC, revised forms and procedures were initiated.

Imagery taken with the 1.6 m Telescope was correlated with the atmospheric characterization sensors at AMOS. Determination of object aspect orientation with respect to the earth's horizon became an important part of the data reduction effort in 1979. AMOS determined orientation of SKYLAB were transmitted to NASA before the satellite's reentry into the atmosphere.

Included in part of the 1979 effort was the calibration and validation of data from the Atmospherics Seeing Monitor. Two methods of calibration were compared. One method which was found to work well for large seeing angles utilized a star image which was driven out of focus by control of the secondary mirror of the 1.6 m Telescope. A second method utilized the illumination of precision pin holes at the entrance to the

Seeing Monitor. Calibration curves derived during the year were forwarded to RADC.

In addition to the CI data base, data reduction/qualification is accomplished for photometric, metric and infrared missions. These missions utilize established validation techniques and reduction programs to yield signature and position data. Early in the year support was provided to a request by SAMSO to reduce additional IR signature data of an object tracked in 1975. The data w~s retrieved from the library and validated. A data package consi.   ng of three missions and including all relevant material was then transmitted to Everett for analysis.

Finally, the LBD Phase II program has resulted in an increase in the related qualification and reduction requirements for AMOS laser range data.

The second data base reduction task is an ongoing evaluation of the existing AMOS data acquisition and reduction capabilities leading to improvements in these capabilities as they are needed in the Phase IV effort.

4.9   Laser Beam Director Program

Early in 1978, AERL completed the efforts described in Modification No. P00052 to Contract F04701-7! ·C-0047 entitled "Laser Ranging Experiments for Experimental System and Test Program Definition, Phase I". The activity consisted of four principal tasks:

1)   Reactivation and improvement of the ruby laser beam director system including bench calibration;

2) Measurements utilizing a retroreflector satellite to characterize range and angle errors;

3) Evaluation of measurement error and observation scenario effects on hand-off accuracy; and

4) Definition of the elements of the next phase of the ongoing experimental program, based on the results of the preceding tasks.

Laser beam director reactivation encompassed transmitter component refurbishing, construction of a receiver instrument package for the 1.6 m Telescope, beam director pointing system repair and calibration, minor ranging system modifications, and associated software upgrades. Bench calibration and a preliminary satellite track verified overall ranging system performance at medium power output (4.5 J in 22 nsec) with 5 arcsecond beam divergence.

Passes of the retroreflector-equipped satellite, GEOS-C, were successfully tracked by AMOS in late Fall 1977, yielding sets of range and angle observations for analysis at AERL. Comparison of these data with high-accuracy GEOS-C orbits provided by the Naval Surface Weapons Center (NSWC) showed range accuracy and precision to be the order of 2 meters and angle precision to be the order of 2 arcseconds. Unresolved systematic errors limited the angle accuracy; this was the subject of a recommendation for Phase II.

A covariance analysis of hand-off accuracy at reentry was completed yielding several parametric plots which span AMOS

capabilities. The parameters were measurement error, measurement rate, measurement interval, and distribution of intervals. The error analysis, together with the demonstrated AMOS performance, showed the feasibility of hand-off to down range sensors.

Results for the Phase I efforts were documented in a final report "Laser Ranging Experiments for Experimental System and Test Program Definition - Phase I", April 1978.

Based upon these results, the LBD Phase II Program was initiated in the late summer of 1978 with the goal of demonstrating a real-time handoff. Specific tasks included:

1) Design, fabrication and installation of new hardware and software necessary for ranging to targets with a low effective scattering cross-section;

2) Development of software to process laser range data with the Kalman filter;

3) Development of software to generate and transmit a real-time handoff message;

4) Ranging on both retroreflector and non-retroreflector satellites to check out the new hardware and software; and

5) Actual generation and transmittal of real-time state vector, based on AMOS range and angle data, to a Kwajalein based sensor.

Work continued towards the accomplishment of these tasks through the first half of 1979. However, during the Spring of 1979, the LBD Phase II efforts were diluted somewhat by added tasks which explored the feasibility of laser illumination of

the failing SKYLAB satellite for the purpose of providing

aspect imagery and metric data while the satellite was in earth

shadow. The requirement to provide a flood illumination of

ruby light, where the need is to maximize the number of photons

in a single pulse, is in conflict with the normal ranging

requirement. For ranging, the goal is to maximize peak power

and minimize pulse length. The illumination mode required

reconfiguration of the laser system and slowed progress on the

basic Phase II program.

In addition, the SANDIA II Measurement Program conducted

in July of 1979 required considerable preparation in addition

to the actual two weeks which were spent in the collection of

measurement data. Preparation included the incorporation of

thermal shielding necessary to stabilize open loop pointing

drifts in the LBD and subsequent testing under various condi-

tions of solar illumination.

By the end of August 1979, tasks 1 through 3 and the first

part (retroreflector satellites) of task 4 of the Phase II

program had been accomplished. In addition, a major milestone

was achieved through the transmittal of an angles-only state

vector for Western Test Range (WTR) Mission GT-69.

In order to complete the remaining tasks, several orbital

and two missile targets were scheduled. Because of poor

weather, only one of the satellites produced useful data.

The results obtained on this target indicated that all new hardware and software performed as designed.

On 25 September, AMOS had planned to obtain and transmit a state vector on the third stage tank from Vandenberg Air Force Base (VAFB) operation GT-138. This was not accomplished due to unavailability of Predictive Avoidance.

On 28 September, AMOS supported VAFB operation GT-70 with the goal of transmitting a range and angles state vector on the Post-boost Vehicle (PBV). All hardware and software systems were operational. The track was excellent after angle interrupts were applied to the Kalman filter. The laser was fired approximately sixty times at the PBV. Unfortunately, optically thick (two-way attenuation was estimated to be about 10^3 based upon video data) clouds obscured virtually the entire trajectory. Since only the order of 10^2 photoelectrons per laser firing were expected under clear sky conditions, no verified laser range returns were obtained. An angles-only state vector was, however, transmitted to Kwajalein and used to point the Kwajalein optical system to within one mrad of the incoming PBV.

By the end of September, therefore, a laser range plus angles state vector had not yet been used to achieve real-time handoff. In addition, the Kwajelein optical system is not, as yet, able to measure the precision of the AMOS handoff (radar data is currently utilized). Discussions with Lincoln Lab and Army Ballistic Missile Defense Advance Technology Center (BMDATC)

personnel indicate that additional AMOS handover efforts would be most valuable in advancing this goal.

In order to accomplish these important objectives, AERL has proposed a continuation of the program through September 1980. AMOS will conduct a total of six laser operations; three against orbital targets and three to sub-orbital targets of opportunity on VAFB test launches. The objectives of these operations will be:

1) Continue to improve and assess the precision and accuracy of the angles plus laser range state vector;

2) Demonstrate this new capability by handing off a suitable target to the optical system at Kwajalein in real-time.

In order to accomplish item 1, three low effective scattering cross-section orbital targets will be used, one prior to each scheduled missile operation. These tests will allow final optimization and evaluation of all hardware and software systems prior to the handoff attempts and will, in addition, provide system performance data to aid in the Lincoln Lab efforts.

4.9.1   Satellite Imaging by Laser Illumination

In an effort to maximize the available observation time for obtaining metric positional and aspect orientation data for the failing SKYLAB satellite, AMOS was asked to examine alternatives to the normal modes of operation used in acquiring image

and metric data. In particular, the possibility of using the AMOS ruby laser was investigated.

Three situations are of interest.

1) Target solar-illuminated, AMOS in shadow. These are normal acquisition windows after sunset and prior to sunrise. No active illumination is required.

2) Both AMOS and the target are solar-illuminated (i.e, daytime). Active illumination may or may not be useful. (See later discussion)

3) Both AMOS and the target are in shadow. Active illumination is clearly of value in this situation, as long as the target is sufficiently above the AMOS horizon. (Existing FAA agreements prohibit laser firing at elevations below 30 degrees).

In developing a scenario for the concept of active illumination of SKYLAB, the following parameters were considered.

1) Target Model (not including solar panels)

   a) Size (cylinder): L = 13 meters, D = 3 meters (optimum aspect);

   b) Reflectance: estimated average ≈0.25;

   c) Range: 0.45 Mm (typical);

   d) Maximum angular subtense at R = 0.45 Mm: 2.9×10^{-5} radians by 0.7×10^{-5} radians.

2) **Laser System Parameters** (Long Pulse Mode)

   a) Energy output: 75 Joules;

   b) Beam angle (containing 75 J): 4×10^{-5} radians;

   c) Pulse length: 10^{-3} seconds;

   d) Wavelength: 0.694 microns.

3) **Receiver** (1.6 m Telescope)

   a) Clear aperture: 1.57 m;

   b) Focal length: 25 m;

   c) Effective collecting area: 1.74 m^2.

4) **Sensor** (ISIT in the Classical Sensor Package)

5) **Expected Return**

   Using the above information and assuming typical
   values for atmospheric and optical transmissions
   and a four percent quantum efficiency for the ISIT at
   $\lambda = 0.694$ microns, the expected return can be
   calculated using the following relationships:

$$N_e = \frac{4E_L \lambda \tau_t \tau_a^2 \tau_r \, q \, A_r \, t}{\pi h c \theta_t^2 \, R^4} \quad \text{photoelectrons/pulse}$$

   where:

   E_L = Joules/pulse from laser into θ_t radians

   θ_t = full beam angle from LBD

   τ_t = transmission of LBD

   λ = 6943 $\mathring{A}$

   τ_a = atmospheric transmission

τ_r = transmission of receiver

q = quantum efficiency of sensor

A_r = effective area of receiver

σ_t = target effective cross section $(\rho_t A_t / \pi \ m^2/ster$

ρ_t = target reflectance

A_t = target area

h = Planck's constant

c = velocity of light

R = target range.

The expected return from SKYLAB is:

$$N_e = 2 \times 10^5 \text{ photoelectrons per pulse.}$$

Comparison to Stellar Observations

It is useful, from the standpoint of an operator attempting to observe the target on a TV monitor, to make a rough estimate of just what the return might look like in terms of equivalent stellar magnitudes. It is recognized that comparison of a monochromatic 10^{-3} second pulse from a resolved object to a broadband signal from a point source will give only approximate results.

Starting with the relationship given in Allen: _Astrophysical Quantities, Second Edition_, page 192 for f_λ (V), an expression for the number of photoelectrons produced by a star of apparent visual magnitude (m_v) during a single frame of the AMOS ISIT (located on the 1.6 m Telescope) is calculated to be:

$$n_e \simeq 10^{(8-0.4 \ m_v)} \text{ photoelectrons per frame.}$$

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Assumptions used are:

Integration time = 4×10^{-2} seconds

Effective bandpass for ISIT = 4000 $\overset{o}{A}$

Effective quantum efficiency in band = 0.06

Atmospheric transmission = 0.8

Optical transmission = 0.64

If we equate N_e to n_e and solve for m_v we get m_v (SKYLAB) $\simeq +6.8$. This value for m_v applies to a system incapable of resolving the target. In the case of the 1.6 m Telescope, the return from SKYLAB is spread over several pixels. N_e should be reduced by a factor of about ten before a proper comparison can be made to n_e.

The result is:

m_v (SKYLAB, LASER ILLUMINATED) $\simeq +9.3$ per pixel

This result suggests that the target can easily be seen by the operator against a dark night sky. If only metric data were required, it would perhaps be advantageous to condense the light on the ISIT with appropriate optics. For example, if the image was minified by a factor of about three then the target will approach the unresolved value of $m_v \simeq +6.8$.

The solar panels will increase the apparent unresolved brightness but not the per pixel value. Strong glints from the panels might hinder rather than help the metric data reduction.

Background Considerations

Against a dark (+ 21 m_v per $arcsec^2$) or even a full moon (+17 m_v per $arcsec^2$) sky, there are no signal to noise problems. For the imaging sensor under these conditions, a narrow band ruby filter is not necessary and was not included in the previous calculations.

Day sky brightness is 10^6 to 10^7 times the dark night sky brightness (i.e, + 6 to + 3.5 m_v per $arcsec^2$ for the unfiltered case). A rough estimate of the effect of, say, a 10 $\overset{o}{A}$ filter centered at the ruby wavelength is that we would reduce the effective background flux by a factor of 400 for the filter bandpass and a factor of 5/2 for the sky spectral distribution. This results in an effective background of about + 13.5 to 11 m_v per $arcsec^2$. Since the value (+ 9.3 m_v per pixel) calculated previously for laser illumination will not be significantly changed, active illumination would be viable during daytime if no other alternative was available.

Since the target itself is also solar-illuminated during daytime, it is of interest to calculate the approximate apparent visual magnitude to be expected. Use of solar data given in Allen (page 172) allows a calculation of the number of photons per m^2 per second incident on SKYLAB in the 4000 $\overset{o}{A}$ band assumed previously. This, when combined with the same system parameters used in the other calculations, results in a maximum value of 4×10^7 photoelectrons per frame when SKYLAB is at a range of 0.45 Mm.

In terms of apparent stellar magnitudes, therefore, the following is obtained:

$$m_v \text{ (SKYLAB, unresolved)} \approx + 1.0$$

$$m_v \text{ (SKYLAB, 1.6 m system)} \approx + 3.5 \text{ per pixel}$$

This result is consistent with AMOS experience. When compared to the unfiltered daysky background numbers stated above, it also shows that SKYLAB can be observed directly during the daytime with the 1.6 m/ISIT System and that laser illumination is not necessary in this case. An appropriate filter (that rejects blue) should improve the signal-to-noise significantly. Needless to say, the 1.6 m Telescope should be properly baffled to minimize scattered light.

The calculations made with respect to active illumination were verified on 4 April 1979 during the first attempt at active illumination. The amount of data recorded during this pass of SKYLAB was severely restricted due to the predictive avoidance (PA) limitations which existed during the time of the pass. However, nine images were recorded by the ISIT TV sensor on video tape and film. Figure 4-41 illustrates the quality of the images. The circle is a reticle pattern inherent in the sensor system. The illuminated image of SKYLAB is clearly distinguishable including three of the solar panels.

This video sensor image was taken under full
night conditions using laser illumination with
the Classical Sensor Package on the AMOS 1.6 m
Telescope which has a focal length of 25.1 m.

Object 6633 (SKYLAB)   4 April 79 UT
Print CLI-004 Fr 2944

Range   -   338 km
Elevation   -   70°
Illumination   -   6943 $\overset{\frown}{A}$
Energy output   -   80 joules
Pulse length   -   1 msec
Beam divergence   -   40 micro radians
Ambient illumination   -   None
                                   (total darkness)

Image sensor   -   ISIT
Recorder   -   MTR-1 Video
                                   to film

Figure 4-41.   Video sensor image (Sheet 1 of 2).
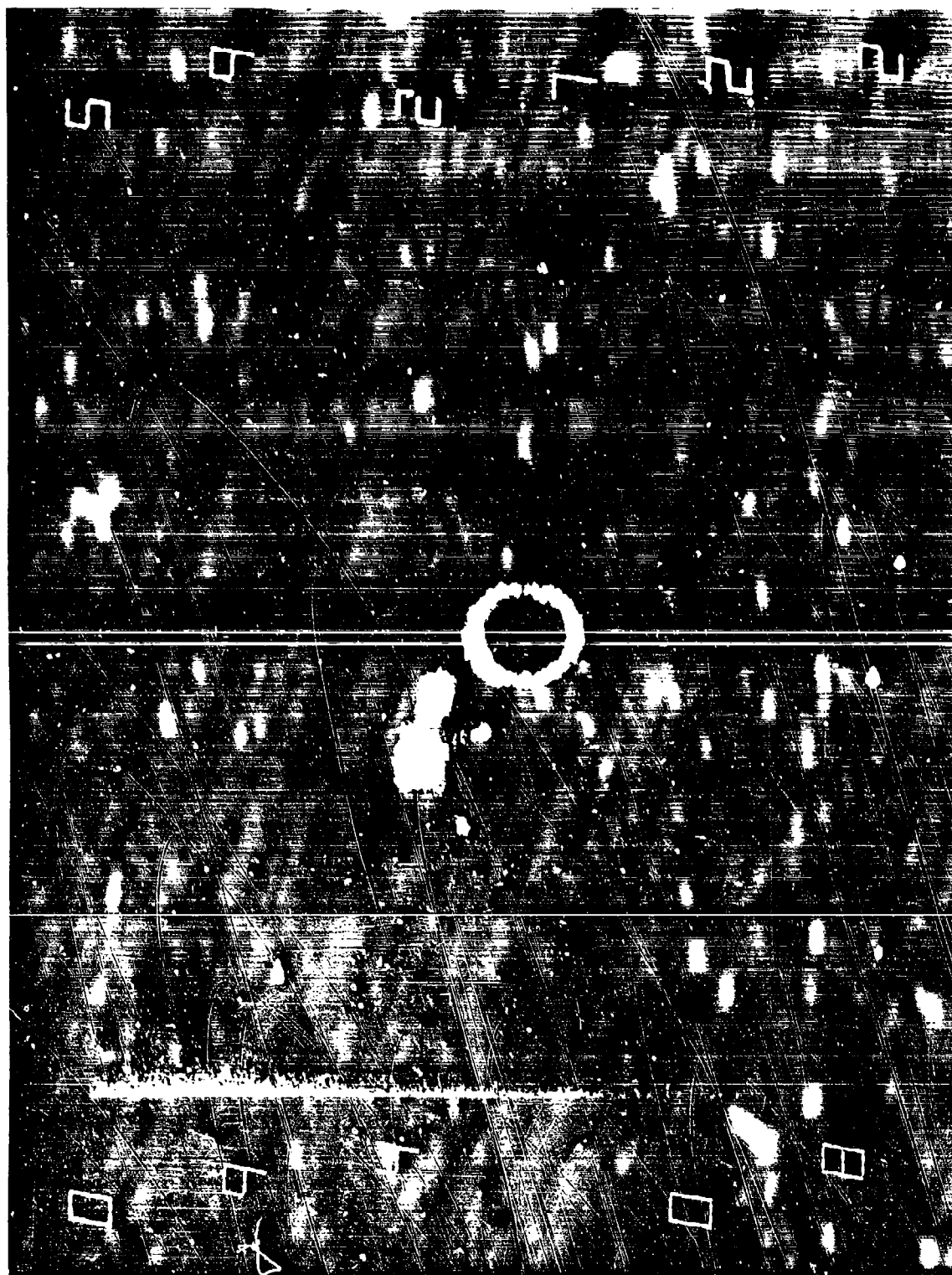
Figure 4-41.   Video sensor image (Sheet 2 of 2).

Prior to this demonstration of active illumination, as a technique for extending available observation time, a daytime passive imaging mission was conducted with success on 13 March 1979. Photographs taken during a 6 April daytime mission which provided exceptional images are included in Section 4.3.3.2.

These two techniques for obtaining image and metric data can be used to extend the optical observation time for many targets to a full 24-hour basis.

APPENDIX A

AMOS GLOSSARY/ACRONYMS

AMOS GLOSSARY/ACRONYMS

AATS	AMOS ACQUISITION TELESCOPE SYSTEM
ABL	ATMOSPHERIC BURST LOCATOR
ABTS	AMOS BREADBOARD TEST SYSTEM
ACONS	AMOS CONTROL SOFTWARE
ACP	ATMOSPHERIC CHARACTERIZATION PROGRAM
A/D	ANALOG TO DIGITAL
AERL	AVCO EVERETT RESEARCH LABORATORY
AF	AUTO-FOCUS
AFCRL	AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AFWL	AIR FORCE WEAPONS LABORATORY
AIDS	AMOS INTERNAL DATA STORAGE
AMOS	ARPA MAUI OPTICAL STATION
AMTA	ADVANCED MULTI-COLOR TRACKER FOR AMOS
ANK	ALPHANUMERIC KEYBOARD
ARPA	ADVANCED RESEARCH PROJECTS AGENCY (NOW DARPA)
ASC	ALL SKY CAMERA
ASTEP	AMOS SATELLITE TRACKING EVALUATION PROGRAM
ATN	AMOS TEST NUMBER
BMD	BALLISTIC MISSILE DEFENSE
BMDATC	BALLISTIC MISSILE DEFENSE ADVANCED TECHNOLOGY CENTER
BTU	BUFFER TRANSFER UNIT

AMOS GLOSSARY/ACRONYMS

CCU   CAMERA CONTROL UNIT

CDC   CONTROL DATA CORPORATION

CDRL   CONTRACT DATA REQUIREMENTS LIST

CG   CENTER OF GRAVITY

CI   COMPENSATED IMAGING

CIS   COMPENSATED IMAGING SYSTEM

CMP   CONTRAST MODE PHOTOMETER

CS   COMMUNICATIONS SYSTEM

CSP   CLASSICAL SENSOR PACKAGE

DARPA   DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

DMA   DEFENSE MAPPING AGENCY

DOD   DEPARTMENT OF DEFENSE

DRS   DATA RECORDING SYSTEM

DTS   DATA TRANSMISSION SYSTEM

ERG   EROS REPORT GENERATOR

EROS   EXTENDED REAL-TIME OPERATING SYSTEM

FAA   FEDERAL AVIATION ADMINISTRATION

FACC   FORD AEROSPACE COMMUNICATIONS CORPORATION

FFIM   FAR-FIELD IRRADIANCE MAXIMIZER

FLIR   FORWARD LOOKING INFRARED

FOV   FIELD-OF-VIEW

GEODSS   GROUND-BASED ELECTRO-OPTICAL DEEP SPACE SURVEILLANCE

AMOS GLOSSARY/ACRONYMS

HP	HEWLETT PACKARD
IC	INTEGRATED CIRCUITS
IID	INTERFACE INFORMATION DOCUMENTS
IR	INFRARED
ISIT	INTENSIFIED SILICON INTENSIFIER TARGET
LBD	LASER BEAM DIRECTOR
LLLTV	LOW LIGHT LEVEL TELEVISION SYSTEM
LSB	LEAST SIGNIFICANT BIT
LTI	LONG TERM INTEGRATION
LWIR	LONG WAVE INFRARED
LVDT	LINEAR VARIABLE DIFFERENTIAL TRANSFORMER
MEV	MASKING EFFECTS VERIlICATION
MIT/LL	MASSACHUSETTS INSTITUTE OF TECHNOLOGY/LINCOLN LAB
MIOP	MISSION INSTRUCTION AND OPERATION PLAN
MOTIF	MAUI OPTICAL TRACKING AND IDENTIFICATION FACILITY
MPM	MONOLITHIC PIEZOELECTRIC MIRROR
MSB	MOST SIGNIFICANT BIT
NBS	NATIONAL BUREAU OF STANDARDS
NEFD	NOISE EQUIVALENT FLUX DENSITY
NORAD	NORTH AMERICAN AIR DEFENSE

AMOS GLOSSARY/ACRONYMS

NORSIC	NORAD SPACECRAFT IDENTIFICATION CONFERENCE
NSWC	NAVAL SURFACE WEAPONS CENTER
PA	PREDICTIVE AVOIDANCE
PBV	POST BOOST VEHICLE
PMEL	PRECISION MEASUREMENTS EQUIPMENT LAB
PRR	PULSE REPETITION RATE
RADC	ROME AIR DEVELOPMENT CENTER
RMS	ROOT MEAN SQUARE
RTAM	REAL-TIME ATMOSPHERIC MONITOR
SAE	SHAFT ANGLE ENCODER
SAMSO	SPACE AND MISSILE SYSTEMS ORGANIZATION
SC	SEQUENCE CONTROLLER
SEP	SAMSO EVALUATION PROGRAM
SOI	SPACE OBJECT IDENTIFICATION
TALO	TIME AFTER LIFT OFF
TI	TEXAS INSTRUMENTS
TM	TECHNICAL MEMORANDA
VAFB	VANDENBERG AIR FORCE BASE
WBS	WORK BREAKDOWN STRUCTURE
WTR	WESTERN TEST RANGE

MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.